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OPERATIONAL RESEARCH

IN

BOMBER COMMAND

Air Historical Branch (1)
Air Ministry.

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PREFACE

The following note was written by Dr. B.G. Dickins, Officer-in-Charge of Bomber Command O.R.S. from September 1941 to September 1945.

'This monograph describes the main work carried out by the Operational Research Section, Bomber Command, from its inception in September 1941, to the end of the war. It has been prepared from contributions by various members of the branch at all levels. It is important to stress that the Section functioned as an integral part of the Command and worked in the closest collaboration with the other branches of the Headquarters. Thus, although this monograph describes the actual investigations undertaken, it is pointed out that the results achieved were in many cases the outcome of teamwork between the Service and scientific staffs. In fact, it is not too much to say that such success as was achieved by the Section was as much due to the receptiveness of the Service as to the efforts of the scientists.'

C O N T E N T S

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CHAPTER I

ESTABLISHMENT AND GROWTH OF BOMBER COMMAND O.R.S.

Early Research in Bomber Command

The first scientific analysis of Bomber Command's operations in World War II was carried out in July 1940 by Mr. A.E. Woodward-Nutt of the department of the Director of Scientific Research, Ministry of Aircraft Production (M.A.P.) following a recommendation of the Committee for the Scientific Survey of Air Warfare. This investigation was directed towards the determination of the causes of bomber losses and a critical examination of the phenomena reported by aircrew during operations. It was hoped that the study would lead to suggestions for reducing our losses, while at the same time providing information which might be of help to our own fighter defences. This survey which was published under the title 'Interception of British Bombers at Night (May-June 1940)' was the first of its kind concerning Bomber Command's operations and was most valuable in presenting all the ascertainable facts; it was decided that a continuous review should be made on the same lines and from August 1940 Dr. B.G. Dickins of the Director of Scientific Research's department paid regular visits to Bomber Command for the purpose. These analyses were issued monthly in a series of reports entitled 'Phenomena connected with Enemy Night Tactics', and later called 'Report on Losses and Interceptions of Bomber Command aircraft' which was continued until the end of the war. The reports constitute a complete record of statistics relating to the interceptions and losses sustained by our bombers together with various conclusions which it was possible to draw from time to time.

The early reports in this series revealed certain facts regarding the efficiency of the bombers' armament which required further detailed study and the Command Armament Officer approached the Director of Scientific Research for the permanent attachment of a scientific officer for more detailed analysis of the problem. As a result of this request, Miss K.M.M. Goggin was posted to Bomber Command in August 1941.

In the meantime, consideration was being given to the provision of radar aids to Bomber Command and although it was to be many months before any equipment became available, Mr. (later Sir Robert) Watson-Watt, the Scientific Adviser on Telecommunications to the Air Ministry, felt the need for a liaison officer in the Command to represent him in the day-to-day deliberations which were going on and to study the operational problems involved. The desirability of such an officer was agreed by the Commander-in-Chief and in April 1941 Professor A.O. Rankine was appointed 'Radio Operational Research Officer'. He was succeeded in July 1941 by Mr. G.A. Roberts of the Telecommunications Research Establishment, who had previously been working in the Stanmore Research Section, Fighter Command. Apart from being concerned with future

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equipments, numerous other Signals problems, in particular the reputed effect of I.F.F. (Identification Friend from Foe) on enemy searchlights, arose and Mr. J.A. Jukes and Miss H. Lang Brown were posted to Bomber Command to assist the Radio Operational Research Officer.

Formation of the Operational Research Section

The value of the work of the scientists attached to Fighter and Coastal Commands had been so amply demonstrated that in mid-1941 the Air Ministry gave consideration to the extension and rationalisation of the scheme. Previously the operational researchers were, with a few notable exceptions, members of the Telecommunications Research Establishment who were merely attached to the Command in which they served. The change agreed upon was to bring operational research more directly under the control of the Air Ministry, while making the groups of scientists now designated 'Operational Research Sections' directly responsible to the Commander-in-Chief of the Command concerned. The personnel concerned were transferred to the staff of the Director of Scientific Research, Ministry of Aircraft Production and seconded to the Air Ministry for attachment to the various Commands. While the Sections were completely independent formations, owing allegiance primarily to their Commands, the closest contact with the M.A.P. and its experimental establishments was essential and was maintained. Liaison with M.A.P. was a special concern of the Deputy Director of Scientific Research 3 (Mr. R.S. Capon) and his staff who throughout the war were of the greatest help to O.R.S's both on technical and numerous personnel matters including recruitment of staff which continually arose. Establishment questions which were the concern of the Air Ministry were handled through the Operational Research Centre (later Deputy Directorate of Science) which was set up under the Assistant Chief of Air Staff (Operations). This department also effected a measure of co-ordination between the various Sections and was responsible, inter alia, for the distribution of the reports prepared.

Thus, following a request by the Commander-in-Chief in August 1941, an Operational Research Section was set up in Bomber Command on 1 September 1941. In view of his long standing contact and consequent knowledge of the Command's operations, Dr. B.G. Dickins was appointed Officer-in-Charge, a position he held until after the cessation of hostilities in Europe. The various other scientists already working in the Command were brought in to form the nucleus of the section together with three additional officers provided by the M.A.P.

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Scope of Research

In asking the Air Ministry for the establishment of an O.R.S. the Commander-in-Chief outlined the scope of the researches which he considered should be undertaken. Broadly speaking, these covered the general study of operations with a view to determining how the efficiency of operations in terms of bombs on the target per aircraft lost could be increased. This objective remained the aim of the O.R.S. throughout the war, although in the later stages, following the example set by Coastal Command, it was extended to include research towards reducing the maintenance manpower required to sustain the effort and other related economic factors. At this stage nobody had any firm ideas on the desirable size of the section. Some plan was, of course, necessary and it was decided to tackle the problems on a broad front. The first distribution of staff duties which was issued on 25 September 1941 was accordingly along the following lines:-

Dr. B.G. Dickins	Officer-in-Charge.
Dr. R.J. Smeed Miss K.M.M. Goggin	Study of bomber losses.
Mr. G.W.M. Stevens	Study of success of bombing operations.
Mr. E.A. Lovell	Study of vulnerability of bombers.
Mr. G.A. Roberts Mr. J.A. Jukes	Study of radar and radio problems.

While the available staff enabled research to get under way, it was abundantly clear from the beginning that a considerable staff would be required if the wide field was to be adequately covered. It was considered, however, that since most of any future staff likely to be obtained would have to be recruited from outside the Government service, the strength would have to be built up slowly. This was inevitable in view of the problems involved in absorbing and training inexperienced staff and was in any case forced on us by difficulties in accommodation. The continual expansion of the O.R.S. coincided with that of the Command and although increases were always anticipated the requirements for office accommodation were usually underestimated. This resulted primarily from the building restrictions imposed on the Command Headquarters as a whole and the long time taken to complete the work. Shortly after the first building had been completed in February 1942, the O.R.S. expansion and that of the Command made it necessary to move part of the staff to accommodation about half a mile away from the main headquarters. This led to considerable inconvenience and loss in efficiency. Plans were made for a new building but it was not until March 1943 that the whole branch came together again. Two extensions to this building were added later, but even so the O.R.S. suffered from over crowding during most of the war; a state of affairs which was not conductive to the best work.

The Establishment

As a result of a preliminary study of the problems requiring investigation it was proposed that the initial establishment of the Section should be: one principal scientific officer, one senior scientific officer, two scientific officers and six junior scientific officers/ assistants grade III, together with a clerical staff of five clerks (General Duty), five clerks (Special Duty) and one tracer. A scientific establishment of 10 officers was approved by the Operational Research Centre in December 1941, and it was also authorised that over the following six months the establishment should be increased to 30 officers (one principal scientific officer, two senior scientific officers, five scientific officers and 22 junior scientific officers/ assistants grade III).

By mid-1942 it was realised that the staff agreed on was insufficient to meet the growing commitments of the section, and in September representations were made to the Air Ministry for an increase in establishment to 41 officers (two principal scientific officers, four senior scientific officers, 20 scientific officers/junior scientific officers and 15 assistants grade II/III. The increase was approved by the Operational Research Committee in October 1942. A further expansion to 51 officers was approved in April 1943, and the maximum of 55 was reached in August of that year. The variation in the strength of the branch is illustrated at Appendix 2 .

Laboratory Assistants

As a result of the growth in the size of the Command, the quantity of data which had to be sifted in any particular investigation became very considerable. The initial establishment of service clerks became in consequence inadequate and in view of the difficulty in obtaining service personnel for the routine extraction and compilation of data, an establishment of 10 civilian laboratory assistant posts was sought and approved in May 1943. Following on the increase in intensity in the Command's operations prior and subsequent to the landings in Europe this establishment was increased to 20 in May 1944. Some of the civilian posts were filled by service clerks but the majority were filled by local recruitment including a number of wives of the officers serving in the headquarters. Many of the laboratory assistants worked only part time, and while this caused some inconvenience, on the whole the scheme worked very well and they made a valuable contribution to the work of the branch. In view of the isolated nature of the headquarters, recruitment of laboratory assistants proved rather difficult and a sufficient number of them was never obtained.

/Clerical Staff

Clerical Staff

In accordance with agreed procedure the clerical assistance to the O.R.S. was provided by Command Headquarters. The initial establishment was five clerks (General Duty), five clerks (Special Duty) and one tracer. This was increased in June 1942 by one in each class and by a further five clerks (Special Duty) in June 1944, who were held against the laboratory assistant establishment. Finally when a number of junior officers were posted overseas in early 1945, the establishment was increased again by one flight sergeant and eight sergeant clerks (Special Duty) in order to replace them. The Service clerks proved very satisfactory on the whole and took a considerable interest and pride in their work. The typists, in particular, were extremely hard working and maintained a very high output throughout the war. /The →

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The Scientific Personnel

Mention has been made of some of the original personnel in the Section and later, reference will be made to officers selected for specific appointments. It is neither practicable nor necessary to give details of the part played by every officer on the strength of the branch. A complete list of officers serving in the branch is, however, given in Appendix I together with the dates of arrival and departure, and an indication of the section to which they were attached. In passing, it must be said, however, that very few of the officers posted to the branch proved unsatisfactory or disliked the work, a state of affairs which was largely due to the care taken by the Ministry of Aircraft Production in selecting the staff.

Organisation of the Section

As explained above, the work of the section was initially divided into four main sections:-

(a) Study of bomber losses.
(b) Study of the success of bomber operations.
(c) Study of vulnerability of bombers.
(d) Study of radar and radio problems.

A fifth section for the study of day operations was added shortly after the branch was formed. This arrangement enabled the field available for research to be adequately explored and work on the main problems to be started. It soon became clear, however, that the study of radar problems was too closely linked to both the study of the success of bomber operations and that of bomber losses for it to be pursued in a separate section. The branch was accordingly re-organized in early 1942 into three sections in the following manner:-

Officer-in-charge O.R.S.	Dr. B.G. Dickins	Head of Branch.
O.R.S.1	Mr. G.A. Roberts	Research into success of Night Operations.
O.R.S.2	Dr. R.J. Smeed	Research in losses in Night Operations.
O.R.S.3	Mr. H.L. Beards	Research into Day Operations.

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This proved a much more satisfactory arrangement, since all matters affecting one aspect of the Command's operations were in a single section. Co-ordination in matters impinging on both losses and successes was, of course, affected through the head of the branch. O.R.S.3 was disbanded in early 1943 when the Command ceased day operations and when these were resumed in mid-1944 the analyses were carried out by O.R.S.1.

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The analyses carried out by O.R.S.2 to determine the cause of bomber losses, the effect of different equipments on the loss rates and numerous other factors necessitated the maintenance of adequate statistics which were not available from normal sources or required by other branches in the Headquarters. The methods adopted are discussed in detail in Chapter 19 of this monograph. It is sufficient to state here that O.R.S.3 was reconstituted as the statistical section in early 1943. This section was run by an Assistant (II) and Service clerks. An enormous quantity of essential data relating to each night sortie flown by Bomber Command from March 1944 onwards, was recorded on Hollerith cards.

Miscellaneous Section

As was to be expected, the O.R.S. was asked to undertake some functions which did not fit in with the organisation described above, or, alternatively, there were some researches which could be pursued without reference to the main problems. These considerations led to the setting up of O.R.S.4 in mid-1942. Each member of this section had a specific job to carry out and reported direct to the head of the branch. The main items covered were investigations into certain aspects of airfield control, research directed towards the use of air photography in the Command, certain training problems and various routine commitments. The research projects are dealt with in the appropriate parts of this monograph and only brief mention need be made here of the following two main routine commitments.

The Bomber Command Quarterly Review

In January 1942, Coastal Command O.R.S. produced a document called the Coastal Command Review. This was seen by the Commander-in-Chief Bomber Command, who immediately commissioned his O.R.S. to produce a similar publication. The desirability of diverting effort from research for this purpose was undoubtedly questionable, although there was no doubt that such a document would be of considerable value for propaganda purposes and could be a useful medium for bringing out some of the lessons learnt. As no suitable serving officer could be found at the time, the O.R.S. undertook to start it off with a view to handing it over to the Service at a later date. It so happened that Mr. B.R. Megaw, an archaeologist, had considerable experience of the right type and he was accordingly appointed editor of the 'Bomber Command Quarterly Review'. The first issue was for the period April-June 1942, and although several efforts were made to hand over the work to the Service, it was not until towards the end of the war that a large proportion of the work was taken over. While many of the articles, were, of course, prepared by other branches of the headquarters, Mr. Megaw wrote a large part of the twelve volumes which were issued, as well as supervising their preparation and publication.

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The Bomber Command Raid Reports

It is well recognised that each major operation carried out by Bomber Command was a major battle and no two operations were identical. It was therefore essential for research purposes for each operation to be studied in detail, for conditions of the operation to be adequately recorded, the success achieved assessed and the causes of losses determined. This naturally required considerable effort and took a considerable time. The investigations generally showed that the only report of a raid, excluding the subsequent reconnaissance reports issued by the Central Interpretation Unit (C.I.U.), which were restricted to a statement of the damage observed, and which was issued by the Intelligence Branch on the basis of pilots reports, did not represent a very accurate statement of results. These reports were the best that could be produced on the evidence available at their time of issue but a permanent and accurate statement was required. Since the O.R.S. had to collect for research purposes the necessary information they were asked to produce a report on each operation for general issue and record purposes. Accordingly as from February 1942, a series of reports known as the 'Bomber Command Night Raid Report' and 'Bomber Command Day Raid Reports' were issued. To start with, parts of these reports had to be written by various members of O.R.S.1 and O.R.S.2, but ultimately the M.A.P. were able to recruit a non-scientist Mr. M. Meyer, to undertake this work. A total of 838 reports on night operations and 328 on day operations were produced, the majority by Mr. Meyer who really tackled what must have become a very monotonous undertaking with much fortitude. With the increasing intensity of operations and only a Laboratory Assistant to help him, the task became a Herculean one and at one time he was at least three months in arrears. In February 1945, however, it was possible to call a halt and get the Intelligence Branch to take over this commitment for future raids.

The reports give the only complete picture available of each operation and include all relevant statistics and brief statements of the weather, route, success, damage and other relevant matters. Amplified statements of the damage inflicted are obtainable from the relevant C.I.U. Interpretation report and details of the tactics and interceptions are given in the 'Interceptions and Tactics' Report which was issued by the Intelligence Branch for each operation.

Radar Research

The increasing use of radar aids to navigation and bombing and the great importance of improving the accuracy and operational use of the various devices available to the Command made it necessary to reconsider the desirability of carrying out the general analysis of

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the success of operations and the detailed research into the performance of radar aids in O.R.S.1. Increase in accuracy could be achieved either by improvement in tactical planning or improvement in the performance and use of the equipment available or a combination of both. The tactical planning had reached a high degree of efficiency by mid-1942 and it was considered that a marked increase in the success of operations could only be achieved by increasing the accuracy of the radar devices available. It therefore seemed desirable that the most suitable officer available should devote all his time to this end. This officer was Mr. G.A. Roberts, who was in charge of O.R.S.1, and it was therefore decided to split O.R.S.1 into two parts, one dealing with the general tactical analysis and visual bombing problems and form under Mr. Roberts O.R.S.5 which dealt with navigational and radar research. Dr. B.G. Peters took charge of O.R.S.1. This arrangement proved completely satisfactory.

Manpower Research

While the major effort of the O.R.S. was directed towards improving accuracy and the continual struggle to reduce losses, some attention was paid to what is now known as administrative research. This type of research was started in O.R.S.6, a new section which formed for the purpose under Mr. K.A. Stott.

O.R.S. Detachments

While the great majority of the staff of the O.R.S. worked at Headquarters, paying visits to units for specific purposes as required, certain officers were detached to lower formations on a permanent basis. The first detachment of this kind occurred in 1942 when service trials of Gee were about to be undertaken by the Command. Following suggestions by the O.R.S., No. 1418 Flight was established to develop the operational use of the device and Mr. J.A. Jukes, who had put forward some proposals on the subject, ~~should be~~ was attached to the unit to assist in the execution of the trials and the analysis of the results. Later, when the Bombing Development Unit was re-formed, Mr. Jukes became the permanent O.R.S. representative at the unit. He was succeeded in January 1943 by Mr. J.K. Marshall. The value of scientific assistance in the planning execution and analysis of trials at the unit was amply demonstrated and in July 1943 this assistance strengthened by the addition of a more senior officer, Mr. N. Mowatt. Apart from providing general scientific assistance in a large proportion of the trials undertaken, some projects, notably those concerned with the development of Window, were largely the responsibility of the O.R.S. personnel. The experience in this and other Commands amply demonstrated that work at the R.A.F. Development Units should be a permanent feature of the O.R.S. organisation.

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Representation at Groups

The analysis and development of target finding technique formed a large part of the functions of the O.R.S. throughout the war, and on the formation of the Pathfinder Force in July 1942 it was clear that while the general analysis would have to continue at Command headquarters, more rapid analysis would be required at the group headquarters if the Pathfinder Force was to fulfil its function of developing target marking techniques. It was therefore felt essential to establish an O.R.S. representative within the group for the purpose of advising the Air Officer Commanding on day-to-day problems, assisting in the quick analysis of each operation and in the development of new techniques. The desirability of this proposal was agreed by the Air Officer Commanding, and in view of his past experience Mr. Jukes was selected for the appointment, which was arranged on a part-time basis until he was relieved of his duties at the Bombing Development Unit in January 1943.

Following a successful O.R.S. investigation into the effect of pilots' experience in the loss rate, the Air Officer Commanding No. 5 Group requested the attachment of an O.R.S. officer to carry out investigations into some of the problems facing the group, and in February 1943 Mr. J. Curry was detached from headquarters for the purpose. Mr. F.J. Lloyd was appointed to No. 4 Group in July 1943, Mr. L.F. Lammerton to No. 100 Group on its formation in December 1943, and Mr. A.W. Pratt and Dr. J.W. Hopkins to Nos. 1 and 6 Groups respectively in February 1944. Dr. J. Hopkins was one of the Canadian scientists sent over to this country for operational research duties.

In addition to general group representatives special damage inspectors were established in Nos. 3, 4 and 5 Groups during 1943, since the reports on aircraft damaged by enemy action required for O.R.S. vulnerability investigations could not be rendered in sufficient detail by the engineer officers in view of the pressure of their normal duties. The damage inspectors, equipped in the first place with motor cycles and later with cars, toured their allotted stations after each operation and rendered most valuable reports on the damage sustained by the aircraft operating. Their reports formed the basis of the work described in Chapter 19.

The establishment of group representatives proved a great success and all Air Officers Commanding spoke very highly of the officers selected. The posts were of considerable responsibility and although the gain to the headquarters branch was not as great as was expected, all the officers performed extremely useful functions so far as the groups were concerned. They were undoubtedly over-worked and had staff permitted they would have been given assistants. This would have enabled the liaison with the headquarters branch to have been

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improved. The delay in establishing the posts was unfortunate but could not have been avoided in view of the general shortage of staff and the absolute necessity of providing experienced and first-class men for the posts.

Bomber Command Bombing Research Unit

Shortly after the Allies were successfully established on the Continent, the Bombing Analysis Unit (B.A.U.) was set up in the Allied Expeditionary Air Force to study the effects of the operations carried out in support of the landing. As Bomber Command had taken a large share in this offensive, the Commander-in-Chief Bomber Command directed that members of his O.R.S. should be associated with this unit. A small party under the Officer-in-Charge O.R.S. went to France with the B.A.U. in August 1944. After working in the Normandy battle area the party became a self-contained team known as the Bomber Command Bombing Research Unit and examined targets in Germany which had been attacked by Bomber Command. An account of its activities will be found in Chapter 7. Mr. H.L. Beards and Mr E.A. Lovell were largely responsible for these field investigations.

Administrative Officer

One further specialised duty in the O.R.S. must be mentioned and that is the establishment of the Section Administrative Officer. With the former assuming a substantial size, the Officer-in-Charge found it essential to have an officer to carry out the normal administrative duties in the branch such as leave, overtime claims, billeting arrangements, accommodation, staff returns, recruitment and payment of laboratory assistants, circulation of incoming reports and distribution of the O.R.S.'s own reports etc. Mr. M.W. Corbett, a schoolmaster who did not possess any scientific qualifications, was selected for this purpose. In addition, he was responsible for maintaining certain routine statistics and records. The Administrative Officer

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the Officer-in-Charge of a great number of troublesome administrative matters as well as acting as his Personal Assistant, and there is no question that such an officer is essential to the smooth running of a large branch. When Mr. Corbett left the Section after the cessation of hostilities, his place was taken by a W.A.A.F. officer. It is doubful if such an arrangement can be quite so satisfactory as the employment of a civilian.

The Final Organisation

It is now possible to set out the organisation of the Section which was finally adopted and which proved to be quite satisfactory. This is given below and includes the sub-sections into which the branch was divided. Most investigations fell within the subjects named and all required continual study in view of the constantly changing tactical situation.

Officer-in-Charge O.R.S.

Administrative Officer

O.R.S.1	Research into Success of Operations.	O.R.S.1 (a)	General tactical success of operations.
		O.R.S.1 (b)	Bombing accuracy and weapon effectiveness.
		O.R.S.1 (c)	Bombing training.
O.R.S.2	Research into Bomber Losses.	O.R.S.2 (a)	Bomber tactics.
		O.R.S.2 (b)	Radio counter-measures.
		O.R.S.2 (c)	Aircraft vulnerability.
		O.R.S.2 (d)	Causes of bomber losses.
O.R.S.3	Statistical Section		
O.R.S.4	General Problems.	O.R.S.4 (a)	Use of night photography.
		O.R.S.4 (b)	Airfield Control.
		O.R.S.4 (c)	Bomber Command Review.
		O.R.S.4 (d)	Night and Day Raid Reports.
O.R.S.5	Research into Radar Aids to Navigation and Bombing.	O.R.S.5 (a)	Use and accuracy of blind bombing aids.
		O.R.S.5 (b)	Use and accuracy of navigational aids.
O.R.S.6	Research into Manpower Economy.		

Detachments

(a) Group Representatives Nos. 1, 3, 4, 5, 6, 100 and Pathfinder Force.

(b) Bombing Development Unit Representatives.

(c) Bomber Command Bombing Research Unit (Field Investigations).

(d) Group Damage Inspectors Nos. 1, 3, 4, 5 and 6 Groups).

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The Position of the O.R.S. in the Command Organisation

The primary purpose of an operational research section is to make a scientific study of the operations of the Command concerned and to draw conclusions which will assist in improving the efficiency of the operations in progress and will ensure that those planned for the future achieve the maximum effect for the effort expended. With this objective in view it was necessary for the O.R.S. to study such subjects as tactics, use of and requirements for navigational and bombing aids, weapon effectiveness, training and aircraft maintenance etc., all of which were the responsibility of one or other of the Command branches. It was, therefore, essential for the O.R.S. to hold a special place in the Command organisation and to work in the closest collaboration with other branches. It was essential also for the O.R.S. to have access to all information relating to past operations and if the maximum use was to be made of their specialised knowledge for them to be consulted in the early stages of the planning of projected operations.

The importance of these requirements was well appreciated by the two Commanders-in-Chief who commanded Bomber Command during the period considered in this monograph and by Air Vice-Marshal Sir Robert Saundby (Senior Air Staff Officer and later Deputy Commander-in-Chief). From its inception the Commander-in-Chief and the Deputy Commander-in-Chief gave the O.R.S. their fullest encouragement and did much to facilitate the conduct of its investigations. Frank expressions of opinion and advice offered, even though not previously asked for, were always welcomed. This attitude did much to establish in the eyes of the Command staff the correct position and functions of the O.R.S. Complete confidence in the O.R.S's ability to help was not, of course, established overnight but apart from a few minor exceptions the necessary collaboration and recognition was quickly forthcoming. The incursion of the scientist into the field of operations, was, after all, an innovation insofar as most of the service staff was concerned and in a large headquarters opposition in some quarters was to be expected. Most of it was short lived and the remainder removed by postings occurring in the normal course of events.

In the same way, as it was necessary for the serving officer to appreciate the place of the scientist in the functioning of the Command, so it was necessary for the scientist to acclimatise himself. Since the scientists were recruited primarily from outside the Government service, they not only had no experience of operations but no knowledge of either aircraft or equipment. And, although short courses were arranged at both the Royal Aircraft Establishment and the Telecommunications Research Establishment for some members of the staff, the knowledge gained was small compared with that of the Command technical staffs. Thus operational research on the equipment side, which was

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not only more difficult to pursue, was restricted by the limited amount of personnel with the necessary background and experience. The scientists had also to learn what was not practicable for both the aircrew and the bomber force as a whole to carry out and also to appreciate the various operational factors which had to be taken into account before conclusions could be drawn from accumulated statistics. That these lessons were well learned is reflected in the fact that no proposal made by the O.R.S. was ever turned down by the Command on the grounds of impracticability. It is, of course, most important for the scientists to attain the closest contact possible with actual operations and with aircrews. For this reason the Officer-in-Charge O.R.S. was normally present at the Commander-in-Chief's daily planning conference and arrangements were made for members of the branch to attend briefings and interrogations as required. The necessity for visits to stations arose, of course, in connection with many investigations. Such visits are an essential part of the practical education of an operational researcher and should be encouraged to the utmost. During the war pressure of work often prevented some members of the staff from visiting stations sufficiently frequently.

In view of its wide terms of reference, involving as it did investigations in the provinces of all branches in both the Air Staff and the Administrative side of a Command, the proper place for the O.R.S. in the Command hierachy is directly under the Commander-in-Chief. For various reasons such an arrangement is not really practicable and in Bomber Command the Commander-in-Chief placed the O.R.S. under the Senior Air Staff Officer (and later under the Deputy Commander-in-Chief when this post was created). At the same time the Officer-in-Charge O.R.S. had access to the Commander-in-Chief at all times. Thus the O.R.S. became a branch of the Air Staff. This position proved to be satisfactory and even at a later date when problems relating to the Air Officer Administration's branches were investigated no difficulty was experienced. On such problems the branch merely dealt with the Air Officer Administration instead of with the Senior Air Staff Officer. It was, however, generally understood that the O.R.S. was available to assist any branch of the Command in any problem, and was situated under the Air Staff primarily for convenience and because its problems were mainly operations. It has now been realised that the administrative problems are of great importance where questions of economy of effort are involved.

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In connection with the position of the O.R.S. in the Command, it is of interest to mention that since the O.R.S. was engaged largely on problems which might be said to be the concern of other branches, particularly in the case of equipment studies, it was often suggested that the scientists should be attached to the various service branches concerned and not be in a separate unit. Such an arrangement would have certain advantages but the majority of problems concerned more than one branch and there was a great advantage in having a single section covering all aspects of the activities of a Command. Further, an economy in manpower would be achieved since within limits the staff could be switched to the problems of greatest urgency at any time. There seems little doubt that a separate O.R.S. branch with the resultant freedom of action is the most efficient and satisfactory arrangement.

The Research Programme

When the O.R.S. was first formed the Commander-in-Chief gave the branch a broad programme of research covering the problems which he regarded as of the greatest importance. The precise items of research necessary to meet this general directive were left to the Officer-in-Charge O.R.S. to decide, and in consultation with the senior members of his staff the detailed programme was built up as the staff increased. From time to time the Commander-in-Chief, his Deputy, the Headquarters branches and external establishments would request specific investigations. These would be given priority but normally the items for research originated in the Section itself.

A detailed research programme was prepared occasionally and submitted to the Commander-in-Chief and Senior Air Staff Officer for approval and guidance as to priorities. It was also forwarded to the Air Ministry.

Issue of Reports

On the completion of an investigation, the results were normally written up in the form of a report together with conclusions and recommendations. It was first forwarded to the service branch or branches concerned for comments, which were then dealt with, and finally forwarded to the Senior Air Staff Officer or to the Commander-in-Chief through the Senior Air Staff Officer for approval and any subsequent action.

Those reports which were approved by the Command were automatically released for circulation. Two series of reports were issued. One, a general series with a wide circulation list dealing with

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matters of general interest, and the other, designated 'S' Reports which were not circulated outside the Command except to those immediately concerned. Some of the investigations were of a strictly domestic nature and the results of those, which sometimes criticised certain aspects of operations, were included in the 'B' series of reports which were not released for general publication. The reports in this series did not necessarily have the Command's approval, but represented the O.R.S's findings and views on the matter.

From time to time members of the staff produced reports which were not considered suitable for publication by the head of the section concerned, and for record purposes these were numbered and classified as 'M' Reports. They did not have the approval of the Officer-in-Charge and represent only the personal views of the author. Such reports, however, became available for consultation.

Thus the researches conducted by O.R.S. during the period September 1941 to June 1945 are recorded in the following series of reports.

(a) General Series Nos. 1 to 141.
(b) 'S' Series Nos. 1 to 243.
(c) 'B' Series Nos. 101 to 237.
(d) 'M' Series Nos. 1 to 160.

~~A list of titles in the four series is given in Appendix~~ .

External Contacts

The work of Bomber Command O.R.S. was closely related not only to that of other branches in the Headquarters and in the Experimental Establishments of the Ministry of Aircraft Production, with whom close contact was maintained, but also with certain other research organisations. The most notable of these were the Air Warfare Analysis Section, Air Ministry; the R.E.8 (Research and Experiments) Division of the Ministry of Home Security; and 'N' Section of the (later Allied Central) Central Interpretation Unit. All these organisations were carrying out, inter alia, operational research into certain aspects of bombing operations for which they were well suited. The A.W.A.S. was responsible for the preparation of charts associated with the various ground-based navigational and bombing aids and the calculation of target co-ordinates, and were in consequence greatly interested in the accuracies of these systems, which was also a function of the O.R.S.; R.E.8 following their studies of the effect of enemy bombing of the U.K., turned their attention to the economic effects of the Allied offensive and were thus interested in the weight of bombs falling on the target. A determination of this, together with research into

/methods

methods of improving it, was, of course a primary function of O.R.S. from the tactical and technical aspects. The O.R.S. therefore provided R.E.8 with much of their operational information, while they in return supplied the O.R.S. with bomb plots for analysis purposes. Bomb plots were also obtained from a section of the Allied Central Interpretation Unit, while 'N' Section, which specialised in the interpretation of night photographs taken at bomb release, developed many interesting methods of providing evidence of the activities of bombers in the target area and the distribution of bombs and markers etc, which were essential to the analysis of raids.

There would have been some advantage had the relevant work of these organisations been done within the O.R.S., but the manpower involved was considerable, and having regard to their other commitments and the accommodation question, it would have been impracticable. As it was a very close liaison was maintained and, on the whole, the arrangement worked smoothly. O.R.S., however, had no responsibility for advising on target selection or for the assessment of the effect of the bomber offensive. Their activities in this field were directed towards increasing the accuracy of attack on the targets selected.

CHAPTER 2

THE TECHNIQUE OF RAID ANALYSIS

Introduction

One of the primary aims of the O.R.S. was to study the success of operations, in terms of the percentage of aircraft despatched which bombed the target, and make recommendations whereby this percentage could be improved. Success is influenced by three main factors, the tactics adopted, the equipment available and the standard of training. The last two factors, while of great importance, necessarily take considerable time to improve, whereas changes in tactics can be made quickly, although desirable changes may be limited through lack of suitable equipment. Available equipment does in fact to a large extent govern the tactics adopted. In order, however, to determine the importance of these factors on the degree of success achieved it is necessary in the first place to make a detailed analysis of a number of individual raids, some of which have not come up to expectation and some of those which have, in order to discover in what respects and why the plan of attack was or was not realised in the event. In this chapter the various techniques of analysis which were developed by the O.R.S. are described. Such analyses not only aim at examining the tactics employed but provide the fundamental data required for comparing the effectiveness of different bombing techniques, and ultimately when sufficient information has been collected enable calculations to be made of force requirements for future operations.

One of the most serious difficulties in raid analysis is the time involved, in particular, the time taken to collect and collate all the necessary information when large-scale operations are involved before the analysis can really commence. In Bomber Command the intensity of operations was such that if the lessons from a raid were to be applied to the following raid, the analysis would normally have to be completed in about 12 hours. Since this was clearly impossible, a quick study of a raid was normally carried out the morning following an operation by the O.R.S. representatives at groups, in particular Nos. 5 and 8 (Pathfinder) Groups, in collaboration with the intelligence and operations staff, using the limited information available at the group, while a longer term analysis was carried out by Headquarters O.R.S. In spite of the delay these analyses often provided information useful for future operations.

The Raid as a Unit for Analysis

Considered as an entity, the individual raid has a more or less complex structure, and if consideration is restricted to its active phase in the target area, a relatively short life. The ultimate units

/of

of which the raid is composed are individual aircraft moving through space at comparable speeds, but along variously contorted tracks. At a critical point in each track the bomb-load is dropped. The raid-as-a-whole is then the aggregate of these tracks considered in their mutual inter-relationship; it is a warp, the strands of which are the individual aircraft tracks. If the actual raid-as-a-whole can be reconstructed and studied, it will be found to differ more or less from the raid as planned; such differences either may be of the order expected (from past experience) by the planners, or they may be critically large so as to be significantly discrepant from the planners' intentions. The problem is to reconstruct the raid, compare it with the plan, and(if possible) to account for major discrepancies between them.

In reconstructing the raid, the chief difficulty is that essential data are both scanty and (when available) variously unreliable. Thus, the analyst is forced to accept a sample drawn from the raid (considered now as a population of data relating to aircraft tracks) and this sample may be inadequate in size and/or biased in nature. ~~Furthermore, the data which are available and which purport to give (say) space and time co-ordinates of the aircraft at the moment of bomb-release, are not uniformly reliable.~~ In any given case it may or may not be possible or practicable to check the reliability of any given datum.

Sources of Data

A variety of documents containing relevant data are available for most raids. Among these the following may be mentioned.

(a) Weather forecasts, made at various times on the day preceding the raid.

(b) Form 'A' issued as the order for the operation by Bomber Command.

(c) 'B' Forms issued as operational orders by Groups to their Squadrons and by the Pathfinder Force to other Groups, and containing details of the projected operation. From 1942 onwards the O.R.S. produced for internal circulation a 'Plan of Attack' based on these forms.

(d) Bomber Command Daily Operational Sorties, giving the size of the raid as despatched and also a first estimate of aircraft missing.

(e) Pathfinder Force Operations Board.

(f) Bomber Command Operational Weather Summary.

(g) Pathfinder Force Provisional Analysis of Operations, and equivalent documents from other Groups.

(h) Bomber Command Intelligence Summary and Narrative of Operations.

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Such documents yielded much useful information, mainly of a qualitative kind, and (supplemented by a target map) gave a rough general picture of what was intended and achieved on each raid. But, so far as raid analysis was concerned, they were of subsidiary importance in comparison with the following three main sources of information.

(a) Sortie Raid Reports. In respect of each operational sortie a detailed report was prepared. These, which will be described in more detail below, gave information on bombs carried and dropped, method of bomb-release, and general conditions in the target area. Above all they were important sources of information about the time of events.

(b) Operational Photographs. These photographs, taken at the time of bombing, were of fundamental importance in that, when plotted and compared with the time and height of bombing given in the Sortie Raid Report (S.R.R.), they enabled the position of the aircraft at bombing to be fixed in space and time with considerable accuracy. They further presented a pictorial commentary on events in the area attacked. The plotting and interpretation of operational photographs demanded much skill and time, particularly in the case of night raids, and O.R.S. leaned heavily on the plotting officers of the Intelligence branch, at all levels throughout the Command, for plottings by ground detail, and on 'N' Section of the Allied Central Interpretation Unit for more complex forms of interpretation.

(c) Daylight Photographic Reconnaissance. As soon as possible after most major raids, complete photographic cover of the target area was acquired in daylight by the Photographic Reconnaissance Unit (P.R.U.). The interpretation of this P.R.U. cover was in the hands of 'K' Section of the A.C.I.U., who regularly produced damage reports and, in some cases, crater plots (showing the position of each recognisable bomb crater). Making use both of 'N' Section (A.C.I.U.) reports on Bomber Command operational photos and of P.R.U. cover, the Research and Experiments department of the Ministry of Home Security (R.E.8) produced more elaborate analyses of damage and also a considerable number of crater plots. Each crater plot was the basis of a statistical analysis of bomb-fall distribution, which at once yielded numerical parameters for the raid in question.

The three main kinds of basic data outlined above now require detailed consideration, since it is necessary that the limitations inherent in each type of analysis should be fully appreciated. Many aspects of photography have not been the direct concern of the O.R.S. but it is nevertheless essential that the background should be clearly delineated so that the work of the O.R.S. can be seen in the right perspective.

Sortie Raid Reports

In respect of each returning operational sortie a detailed report was obtained, from interrogation by the Intelligence branch at squadron level, and submitted through Groups to Headquarters Bomber Command. The precise form of this report varied with the changing requirements of the branches interested, in particular the O.R.S., and questions no longer required were

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deleted as soon as possible in order to spare both tired crews and the hard-pressed intelligence officers. Originating with a discussion at the Group Commanders' Conference of 9 August 1941, and following closely the existing Form 'C' used in No. 5 Group, the Sortie Raid Report was tried out in No. 5 Group during November and December 1941, and was adopted by all operational groups as from 1 April 1942.

On page 23 is the pro forma of the Sortie Raid Report (S.R.R.) used from November 1943 until (with minor modifications) the end of the war. It will be seen that Section 'A' is concerned mainly with identification and with data ascertainable before take-off. Section 'B' was intended for items of immediate importance (e.g. enemy ship sightings) which were telephoned to the group at once and did not, in fact, appear on the S.R.R. at all. Section 'C' was used as a guide for interrogation, replies being given only where applicable. Moreoever, the headings of Section 'A' were not repeated on the S.R.R. itself, and the completed document resembled the specimen shown on page 24.

A comparison of these two forms will, in most cases, make the S.R.R. self-explanatory, but the following commentary may be helpful.

(a) The symbol (30 plus 8) after the Captain's name meant that he had completed 30 operations in his first tour, and eight in his second; such data were used as evidence of experience.

(b) The target given in Section 'A' is the briefed target; that in C(1) is either the target actually attacked or, in the case of abortive sorties, the place, time, height and reason for abandoning the mission.

(c) The load dropped, C(5), was quoted by the Pathfinder Force and by the Main Force in all cases where the load was split up between two or more aiming points.

(d) Under C(6) was to be given the colour of marker bombs and, for target indicators the time at which it was seen to cascade; the latter information was used in tracking down decoy target indicators.

(e) C(7) would be answered in place of C(6) in such cases as bombing on dead reckoning from a previously identified landmark, or bombing blindly by radar aids.

(f) The bomb-load dropped was ascertainable from the load carried (Section 'A') less any returns under 9(a) or (b).

(g) Questions C(10) and (11) were later discarded.

Different parts of the S.R.R. were of importance to various branches at groups and at command headquarters, and to different sub-sections of the O.R.S. So far as raid analysis is concerned the data of main importance were:-

/(a)

(a) target attacked,

(b) bombs dropped on target,

(c) time, height, heading and airspeed at bomb-release,

(d) what was in bombsight (or other method of bombing),

(e) bomb aimer's and pilot's reports.

The aircraft was identified by squadron number and aircraft letter.

From this information a time histogram of the raid was constructed, known from its size as the 'Table-cloth', in which each vertical column represented one minute and each unit cell one sortie. Each half-inch square cell contained the identification (e.g. '101.G'), a coloured symbol indicating the point of aim (e.g.green target indicators), a symbol to show if that aircraft's photo had been plotted, and in some cases a special bomb-load symbol (e.g. indicating H.E. only).

Above the Main Force histogram the Pathfinder H.E. aircraft were separately shown, with an additional symbol to indicate the kind of markers dropped. In the case of (say) a green target indicator of average burning time, seven minutes, a horizontal green line would be drawn extending over seven columns. An additional horizon row of cells would show (by small dots), minute by minute reports of the cascading of (say red) target indicators.

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SORTIE RAID REPORT

Section 'A'

Group: | Aircraft (A/C) Squadron and Letter.

Date: | Station and Raid Report No.:

Bomb load and fusing including special flare loads | A/c Type and Mark:

Special Equipment: | A/c Number:

Target: | Captain: | No. of Ops:

Navigator's Watch Error:(1) | Function:

Section 'B'

Immediate reports.

Section 'C'

(1) Target Attacked:

(2) Weather over target at the time of bombing:

(3) How did you identify the target:

(4) Time of attack (to nearest minute): height (to nearest thousand): heading (magnetic): Indicated airspeed (in m.p.h.):

(5) Load dropped on target:

(6) What was in bombsight:

(7) If bombsight not used, how did you bomb:

(8) Bomb aimer's description of target area:

(9) (a) If any bombs, flares or target indicators were jettisoned, state place, time, and height and reason:
(b) If any were brought back, give details and reason:

(10) Give place and time where route or warning markers were seen or dropped and remarks as to effectiveness:

(11) What (if any) of the special equipment mentioned above was:-
(a) unserviceable:
(b) not used:

(12) If a defect affected the result of the mission, state which component or equipment failed:

(13) Was the aircraft damaged by (a) fighters, (b) flak, (c) other causes, e.g. falling bombs, collisions? If so, give brief particulars:

(14) If you knowingly deviated from the ordered route, state the route taken and give the reason for the deviation:

(15) Describe effects of any adverse weather encountered, e.g. ice, thunderstorms, electrical storms:

(16) Pilot's personal report:

(17) Initials of Interrogating Officer: Time of Origin:

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(1) Pathfinder Force only.

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SPECIMEN COPY OF RAID REPORT FOR MAIN FORCE

Section 'A'

No. 4 Group
2/3 October 1943
2 x 1000 (medium capacity) (Tail Delay ~~timed detonator~~) .025 secs.
24 x 30 Incendiary, 690 x 4 Incendiary
30 x 4 'X' Type Incendiary
Gee Mark XIV/BS, Boozer,(1) Monica,(2) H2S
Munich.

102 G
Pocklington 442
Halifax II A
LW 246
P/O Smith (30 + 8)

Section 'C'

(1) Munich
(2) 2/10 to 3/10 (strato cumulus) 5000 ft. Visibility excellent.
(3) Red and Green (target indicators) seen cascading. Checked on dead reckoning run from north tip of Wurm See, which was identified visually.
(4) 2131 hours. 18000ft: 052M: 270 m.p.h.
(6) M.P.I. of Green Target Indicators. One of these seen to cascade at 2129 hours.
(8) No Red Target Indicators seen at time of bombing: Greens well concentrated with exception of one about 5 miles to east. Much smoke in target area.
(9) (a) 1 x 1000 MC hung-up and was jettisoned 49 12N 09 34E 2202 hours 19000 ft.
(10) Ruby Spot fires seen near Wurm See on run at 2126 hours. These were scattered over an area of several square miles.
(11) H2S Monica
(13) Port wing damaged by incendiaries over target. Believed flak damage to starboard inner engine 40 miles short of target, 2120 hours 19000 ft.
(15) Severe icing en route, lost height 2000 ft. This caused us to be several minutes late in reaching target.
(16) Fighters and searchlights very active in target area. Coned for three minutes after bombing. At 2135 hours Lancasters passed 200 ft below.
(17) LCL. 0712 hours 3 October.

The completed 'Table-cloth' gave a clear birds-eye view of the raid as a whole, extended in the time dimension, and also provided numerous useful indexes such as aircraft bombing per minute, proportion plotted per minute, aiming at (say) Red target indicators per minute etc.

Difficulties of size and colour preclude the reproduction of 'Table-cloths' in this monograph, but large numbers of them are filed at O.R.S. Bomber Command along with other raid data, in chronological order.

Another useful document deriving from the 'Table-cloth' was the photographic Plotting List prepared for each raid. Here, against aircraft listed in time-order of bombing were given:-

(a) Method of plotting, if any (e.g. by ground detail, light tracks etc.).

(b) Plotted position as distance and bearing from aiming point.

(c) Aircraft heading.

Originally prepared by hand, these lists were later provided using a Hollerith tabulator, from punched cards, each card representing one sortie and punched

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(1) Tail warning radar device against enemy aircraft interception equipment.
(2) Tail warning radar device against enemy night fighters.

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as a result of coding the Sortie Raid Reports.

Operational Photographs

At the time the O.R.S. was established, night photography was in its very early stages of introduction into Bomber Command. A few aircraft had been equipped with suitable cameras and an occasional successful photograph was being obtained. These all too infrequent photographs gave the badly needed information of where an aircraft actually bombed and opened up an enormous and profitable field of operational research. Previously, the only information available on the success of an operation came from crews reports and subsequent P.R.U. cover. All too frequently cover of the target showed little damage and nobody knew where the attack fell. With the introduction of night photography this information became available and it became possible to determine the causes of failures and to improve the effectiveness of operations. The provision of this essential data in sufficient quantity did not occur over night. There is a story of great difficulties successfully overcome, both by the photographic branch of Bomber Command in securing adequate photographs taken with bombing, and in the interpretation and plotting of such photographs by the Photographic Interpretation Section of the Intelligence Branch Bomber Command and by 'N' Section of the Allied Central Interpretation Unit (A.C.I.U.).

In the earlier daylight raids, cameras carried by selected crews were manually operated by the pilot, ten seconds after bomb-release. Resulting photographs often showed the actual bomb strikes and in that case gave accurate information as to where the bombs fell.

Night Photography

At night, the difficulty was to secure a photograph of the ground, at the point where the bombs fell, illuminated by an almost instantaneous photoflash, dropped at the same time as the bombs. The situation is that, after release, the bombs trail behind the aircraft, and the photoflash (having a lower terminal velocity) behind the bombs. Ideally, the photoflash should ignite at a definite pre-determined instant of time at a reasonable height above the ground, and if possible outside the field of view of the camera. There is a further requirement that the aircraft should continued in straight and level flight until the bombs have struck. The whole situation calls for accurate timing in the launching and ignition of the photoflash and in the operation of the camera.

After many experiments, including an attempt to secure strike photographs as in daylight with backward-pointing cameras, the problem was solved by introducing an automatic camera control and photoflash release actuated by the bomb-release key and introducing a time delay (varying with height) such that the vertical camera secured a photograph /of of the point where the bombs (still in the air) would finally strike, if the aircraft continued in straight and level flight. Timing-errors in the photoflash were such that this 'bombing frame' had to be exposed for eight seconds in order to be reasonably sure of recording ground detail. The result was that fixed sources of light on the ground were recorded as elongated streaks; these were straight if the aircraft's course was straight during the eight seconds, but variously contorted by aircraft manoeuvres. The A.C.I.U. perfected a method of deducing manoeuvres from the streak-pattern on the bombing frame and adjacent frames. ~~This information was used by the O.R.S. in another connection. (See Chapter page).~~

Photo-Dispersion

Later in the war, the barometric fuse on the photoflash was replaced by a more accurate clockwork fuse, which enabled the exposure time of the bombing frame to be reduced to four seconds. Even with straight and level flight, however, errors in the timing of the flash led to errors in taking the centre of the bombing frame as the point of bombfall. If the aircraft changed course before the photoflash ignited, the error would be increased, and if it was then in an attitude of bank or tilt, throwing the camera axis out of the vertical, the error might be very great.

The probable distribution of bombs about the centre of a night photograph is fully discussed, and diagrammatically illustrated, in Bomber Command O.R.S. Report No. 7, which shows that, with the camera axis vertical at photography, bomb ballistics and evasive turn of the aircraft between bomb release and photography will lead to half the bombs being less than half a mile from the plumb point. The effects of variation in height and airspeed, and of normal amounts of tilts and/or bank were also discussed in this report.

If, on a given raid, these plotting errors are random in direction and amount they do not significantly affect an estimate of where the raid is centred. They might, however, make the raid appear more scattered than it was in fact. It was therefore desirable to secure a quantitative measure of this 'photo-dispersion' effect, but it was not until the last year of the war that the O.R.S. obtained the data necessary to do this.

Tilting of Camera

The Type 35 camera control, adjustable for height of aircraft at bombing and showing the required photoflash fuse setting in seconds (the flash was fused to explode at half the height), worked well enough

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with mixed loads of incendiaries and high capacity bombs with a terminal velocity (T.V.) of about 800 feet per second dropped from 20,000 feet on area targets. Depending on the bomb load, there were slight systematic errors involved in taking the centre of the bombing frame as the point of bombfall, but these were quite negligible in comparison with the random scatter of bombing and with the errors involved in plotting aircraft bombing from this height. But from early 1944 the series of campaigns directed against tactical targets were carried out from much lower height, leading to increased accuracy of both bombing and plotting, and with 500 pound or 1000 pound medium capacity/general purpose bombs having a T.V. nearer 1600 feet per second. The result was a quite serious error in plotting.

The O.R.S. drew attention to this situation and devised a series of corrections to be applied to the plotted position, depending on height of bombing, T.V. of bombs, and length of stick (the centre of the stick was to be plotted), and making necessary wind corrections. ~~(See Bomber Command O.R.S. Memo No. M.)~~ (1) The Photographic Intelligence Section had insufficient staff to apply these corrections, however, and suggested instead that the tilting of the camera forward through 8° (with which No. 5 Group were experimenting) should be made general. The O.R.S. reported favourably on this, ~~in Bomber Command O.R.S. Memo No. M~~ (2) and it was suggested that the photoflash settings should be changed to give still greater accuracy, and also that the first bomb of the stick rather than the stick centre should be plotted, since a wide variation of stick spacing was coming into use. In view of the fact that trials on a new photoflash were in progress, and that these, if successful, would in any case lead to a new set of photoflash fuse settings, the Photographic Branch rejected the suggested changes in fuse settings in favour of varying the camera tilt as follows:-

Operation Height (feet)	Camera Tilt
Up to 9,000	8° forward
10-14,000	5° forward
16-20,000	3° forward.

This was officially laid down in a postagram dated 22 June 1941.

Although theoretically adequate, this scheme did not work well in practice for the following reason. Under high pressure of operations, with often a last-minute change of target and of briefed bombing height, ground crews could not be relied upon to make the necessary changes in tilts. It was not merely that, in any given case, the camera might not have been at the correct tilt, but that the plotters could not know whether it was so or not. The large but calculable errors of the

/vertical-camera

(1)

(2)

vertical-camera plot were replaced by an unknown proportion of incalculable errors. This became particularly serious in No. 3 Group since the O.R.S. was striving for accurate analysis of their Gee-H attacks; the vertical-camera was therefore restored throughout that group in a letter dated 21 February 1945, and throughout the rest of the Command with effect from 7 April 1945. A new dial was designed for the Type 35 camera control, the difficulty of weapons of different T.V. being met by providing separate dials for those of T.V. respectively less and more than 1200 feet per second.

Camera Sequence

The night camera had no shutter other than the capping blind which covers each wind-over, so that film is continuously exposed from take-off to return. It was therefore necessary to wind over a new piece of film at the beginning and again at the end of the eight (or four) seconds bombing exposure. The camera was often operated repeatedly in order to photograph interesting phenomena, and some of these additional frames also recorded ground detail lit by the photo-flashes of other aircraft. There was thus the problem of identifying the bombing frame; this, in fact, was solved by sandwiching it between two short one quarter second exposures, operated by the automatic camera control, though these short exposures were primarily introduced to eliminate fogging of the bombing frame.

The actual sequence of photographs comprised in one complete camera operation was as follows (the day-camera sequence is also listed here for convenience; it will be referred to below).

Frame No:	Night Camera	Day Camera
1	Start frame (fogged out) with test wind-over to:	Start frame.
2	Indefinite exposure from base to target.	Test frame.
3	Bomb-release frame (exposed) about 30 seconds.	Bomb-release frame.
4	¼-second pre-bombing frame.	Bombing frame.
5	4-second bombing frame.	Bombing frame.
6	¼-second post-bombing frame.	5.6 seconds after No. 5.
7	Indefinite exposure from target back to base.	1.6 seconds after No. 6.

Prior to the end of 1943 there was no bomb-release frame, so that No. 4 was then the bombing frame, and at that time was exposed for 8-seconds. The cycle operated by the Type 35 control (Frames No. 3-7) was usually repeated in the target area, at the will of the air bomber, to furnish additional cover, though the 'bombing frame'

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of this second cycle would not usually show ground detail since no second photoflash was dropped. In a proportion of cases, however, ground detail illuminated by the photoflashes of other aircraft was visible.

Plotting by Light Tracks

In a concentrated fire raid, there quickly formed a dense carpet of incendiaries burning in the ground, and the intense light from these might completely 'fog' the ground detail hit by the photoflash. It follows that aircraft bombing the centre of such a concentration had a smaller chance of being plotted than those on the edge. Thus, the picture of the raid given by a plot of ground-detail photographs was pessimistically biassed in favour of stragglers and the raid appeared more scattered than it was. This vitiated any attempt to get a quantitative measure of scatter from photographs plotted by ground detail. Early in 1942 the C.I.U. ('N' Section), however, developed a method of plotting aircraft by means of the pattern of incendiaries on the fogged-out bombing frame, which overcame this difficulty. The method was greatly complicated by the fact mentioned above that the points of light (incendiary candles) appeared on the bombing frame as contorted streaks. Fortunately, the quarter-second frames, whose purpose was solely to eliminate fogging of the bombing frame sandwiches between them, usefully recorded incendiaries almost as points, and so revealed their pattern.

Slow-operating Shutter at Night

Certain aircraft were fitted with the so-called 'slow-operating' shutter (the adjective was applicable to daylight conditions) which, set working on approach to the target, automatically took a 1/25 second exposure every six seconds until switched off. The effect of using this at night was to produce a series of line-overlaps crossing the target, and recording the patterns of incendiaries, fires, and target indicator bombs burning on the ground. These line-overlaps were of the greatest use to 'N' Section of the A.C.I.U. in plotting aircraft by light tracks; they unfortunately had the defect that it was practically impossible to identify a bombing frame for the aircraft in question, and therefore impossible to plot its own position at bombing.

Adequacy of the Plotted Sample

It was of great importance to determine whether the photograph plotted by ground detail and light tracks represented an unbiased sample of the raid as a whole, and this problem was investigated by the O.R.S. In raids between 10 and 26 June 1941, of 1385 sorties

/reporting

reporting attack on the primary target, only 17 per cent secured technically successful photographs and only 10 per cent were photographs taken with bombing; this sample was too small to sustain adequate analysis. By April 1942, 93 per cent of despatched sorties were fitted with cameras, and within a few months the figure was 100 per cent. By August 1942 the C.I.U. was providing a substantial proportion of plottings by the new method of plotting by light tracks for certain raids. By the time of the Ruhr campaign in the second quarter of 1943, 50 per cent of the aircraft reporting attack under clear conditions were actually plotted, half by ground detail and half by light tracks, and still more might have been plotted if time had permitted. From this time until the end of the European war the proportion of aircraft plotted, on night raids, steadily increased until by the end of the war it was as often as not over 80 per cent. As a result of a careful investigation, it can be said that from the beginning of 1943 onwards operational photographs yielded an unbiased sample of a size adequate for quantitative analysis, on most clear-weather raids and on a fair proportion of moderate-weather raids.

Poor-weather raids [redacted] presented a difficult problem not only operationally but also in analysis, owing to the paucity of operational photographs tied to ground detail. The C.I.U. ('N' Section) devised a complex method of plotting by cloud pattern which took into account the drift of clouds as well as the movement of the aircraft above them. From such cloud plottings it was possible to assess the concentration of a raid in space relative to the ground, but without knowing where the raid was centred, unless a break in the clouds permitted ground-detail to be recorded. The only other adequate method for analysing poor-weather raids, by crater plots, will be referred to below in the section on daylight photographic reconnaissance.

← Colour Film

The introduction of colour film in October 1943 had the great advantage that the colour of target indicator bombs could be assessed, but this film was so much slower than the standard night film that there was a danger of ground-detail being lost. This danger was overcome by fixing a short length of colour film on top of the standard film so that it covered the earlier frame up to the first quarter-second frame, but left the bombing frame unobscured.

Daylight Photography

With the transfer from Bomber Command of No. 2 Group at the end of May 1943, daylight bombing operations ceased until June 1944, but in the next three months daylight operations accounted for more than 50 per cent of the Command's effort, and they continued to the end

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of the war. Operational photographs presented far fewer problems in daylight. The day camera was similar to the night camera, except that a shutter was fitted and instantaneous exposures replaced the long night exposures. One such exposure was made at the time of bombing release (see above).

Forward Plotting from Bomb-release Frame

The bomb-release frame recorded ground detail at a time in the bombing run when the aircraft was most likely to be flying straight and level. If the centre of the bomb-release frame could be plotted, and the height, airspeed, and track of the aircraft were known, the point of bombfall could be forecast by using ballistic tables. It was shown that, in comparison with a standard raid-plot made from the bombing frames, a plot made by this method of forward plotting was less scattered and showed much closer agreement with a plot of the actual bomb craters. Accordingly, not only was this method of forward plotting devised and used by O.R.S. for plotting daylight raids, but also it gave for the first time quantitative evidence on the amount of 'photo-dispersion' due to plotting from the bombing frame (see above), and so allowed a correction to be made in those cases where no bomb-release frames were available, as in night raids. This correction for photo-dispersion is described in Bomber Command O.R.S. Report No. 136,(1) and is discussed further on page 47 .

Unfortunately, there were fewer plots of day raids than there might have been. The photographic interpretation branch of Bomber Command Intelligence did not consider that its terms of reference covered the plotting of day raids, and, while the A.C.I.U. undertook the plotting of target indicator marker bombs for a few raids and also plotted some bad weather raid by cloud patterns, they were unable through pressure of other work to accept a commitment for routine plotting. With a few exceptions, the plots of day raids which became available were made by the O.R.S., it was undertaken in this case for selected raids so that investigations could be made into day operations which at this time represented about half the Command's effort.

Among the groups, No. 4 Group was especially interested in the plotting of day photos by the method of forward-plotting from the release-point frame, and in co-operation with them the full details of the method were worked out by the O.R.S. in July 1944. The method was issued to groups in Bomber Command O.R.S. Report No.B.224 (2) together with tables giving the forward-plotting distance in yards, for bombs of T.V., 1,600 feet per second and 800 feet per second respectively, for various

/operational

(1) 'The Measurement of Concentration of Bombing from Photographic Plots.' (A.H.B./IIH/258/1/290B).

(2) 'Assessment of Bombing Accuracy on Daylight Operations.' (A.H.B./IIH/241/22/12)

operational heights from 4,000 feet to 20,000 feet and for camera tilts of 0°, 3°, 5°, and 8° forward; there was also a table of wind correction factors.

Tilt and Bank at time of Photography

Daylight photographs also enabled the O.R.S. to work out methods of determining the tilt and bank of the aircraft at the time of photography, and thence the plumb-point. Theoretically sound, these methods were too time-consuming for practical use, in a very busy period, except in cases of critical importance. Bomber Command O.R.S. Report No. 106 gives several related methods of finding the angles of tilt (fore and aft) and bank (side to side) of the camera plate at the time of photography, based on the plotting of several points on the photograph and relating measured distances between these points on the print to the corresponding ground-equivalents. Bomber Command O.R.S. Report No. 108 (1) gives a brief graphical method for determining the plumb-point of the aircraft from the found angles of tilt and bank. These methods assumed the use of the standard eight-inch lens camera. Bomber Command O.R.S. Report No. 114 (2) selects the best of the tilt/bank methods and extends it to cover eight-inch, seven-inch and five-inch lens cameras, also covering the plumb-point determination, and thus replacing the two earlier reports for practical purposes.

Plan Position Indicator Photographs

The determination of the accuracy of blind bombing with equipment such as H2S was of great importance, and the O.R.S. pressed strongly for the development of a suitable method for photographing the Plan Position Indicator (P.P.I.) at the time of bomb release. If this photograph could be accurately plotted by means of some recognisable feature, the position of bombfall could be calculated as in plotting forward from the daylight release-point frame. Owing to the vagueness of the presentation, plotting by this means was not thought to be very accurate, but in view of the great value of being able to determine the position of aircraft above cloud, it was desirable to secure a measure of the accuracy achievable.

The accuracy of plotting H2S photographs was determined by comparing the positions of aircraft at bomb release plotted respectively from the P.P.I. photograph and from the standard bomb release frame (see above) obtained during the daylight operations, and also using the bombing frame during night operations. The problem is discussed in Bomber Command O.R.S. Report No. 148 (3) from which it will be seen that the radial standard deviation of plotting by this method was of the order of one mile.

/Daylight .....

(1) "Plotting the Plumb Point in Air Photographs" (A.H.B./II/39/1).
(2) "Tilt, Bank and Plumb Point from Air Photographs" (A.H.B./II/39/1).
(3) "The Accuracy of Plotting Photographs of the H.2.S. P.P.I." (A.H.B./II/39/1).

Daylight Photographic Reconnaissance

The main purpose of daylight photographic reconnaissance is, of course, to provide information on the damage inflicted on the target. Whenever P.R.U. cover of Bomber Command targets proved adequate in quality, a provisional statement on damage was issued by 'K' Section of A.C.I.U. and this was often followed by a more detailed statement, both largely in qualitative terms. Quantitative assessments of damage, of the greatest value in determining effectiveness of weapons as well as in measuring the amount of damage inflicted, came from R.E.8, Ministry of Home Security (later transferred to the Air Ministry). This, in itself, constituted a different form of raid analysis, and there was a fertile field of research, partially explored by R.E.8 in correlating this type of analysis with the operational raid analysis undertaken by the O.R.S. But data for the latter were also derived from daylight photographic reconnaissance in the form of crater plots.

Crater Plots

In some ways a crater plot provided a far more accurate picture of raid than a plot of night photographs, since the actual bomb craters were recorded and the various errors inherent in plots of photographs were therefore eliminated. Also, ideally, the crater plot shows all the live bombs dropped, whereas at best the plot of photographs recorded the position of only a sample of the attacking aircraft. Crater plots, nevertheless, suffered from a number of limitations, none of which applied to plots of photographs. The principal limitations were:-

(a) The P.R.U. aircraft attempted to photograph the target attacked and if the raid was unduly dispersed or badly centred the photographic cover obtained might not include all the bombs dropped, and this fact complicated detailed analysis.

(b) It might be difficult or impossible to recognize all the craters present. It was, in fact, almost invariably the case that not all the bombs that exploded within the area of a crater plot were plotted; the average proportion plotted was of the order of 80 per cent as far as can be ascertained by estimating the number of bombs that fell on the area of the crater plot from the distribution of the night photographs and making an allowance for unexploded bombs. The principal factors which affected the proportion of bombs which could be plotted were the quality and scale of the photographs, the nature of the terrain, wooded country and heavily built-up areas being the most difficult, and the density of bombfall. The most important point was that more craters tend to be missed in the central parts of the bomb distribution where the density was greatest and as a result the spread of bombs tended to be over-estimated.

(c) The crater plot, of course gave no evidence of how the raid progressed, and it could not therefore be used for that time analysis of raids which was often so illuminating an analysis of night raids.

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In the case of large town targets the preparation of a crater plot was a long and difficult task. It was considered that, on balance, the plot of photographs was sufficiently accurate and far less time-consuming. Nevertheless, crater plots were prepared by R.E.8 for several raids on town targets, and a number of these for the specific purpose of assessing major raids carried out in bad weather.

In the case of small targets, the inaccuracies of plots of photographs became important and the crater plot was a better source of data on most counts. Thus, for example, a series of complete crater plots was prepared by A.C.I.U. ('K' Section) for the attacks on railway marshalling yards in 1944.

Twenty Acre Densities

A method of obtaining a rapid measure of success from daylight reconnaissance photographs which was used, was to count the number of craters within a circle of an area of 20 acres centred on the aiming point, and then to express the result in terms of bombs per acre per 1,000 bombs dropped. For this method no crater plot was required since the circle could be drawn and the craters counted directed on the photographs. This method only provided data which could be used for comparing raids with one another, since it could not be assumed that there are no missed craters. Even when these results were used for comparative purposes it was necessary, if one was not to be misled, to bear in mind that differences in the proportion of craters detected would occur. Nevertheless, the information derived from these counts for 207 raids carried out in the summer of 1944 proved very useful.

Fire Mosaics

A further source of data should be mentioned here because, although derived from operational photographs and not from P.R.U. cover, it was strictly analogous to a crater plot; the fire mosaics or plots of incendiary sticks prepared by A.C.I.U. ('N' Section). These should be sharply distinguished from plottings of aircraft by means of light tracks, since they have something approaching the accuracy of crater plots if the stick pattern can be tied to ground detail, and they have the advantage over crater plots that their development in time can be followed. In the matter of tying the incendiary plot to ground detail it should be pointed out that, in the later years of the war, the main streets of a town were often clearly discernible, picked out in points of light from incendiary candles. This was because incendiaries in the streets were clearly visible while a proportion of those which fell on adjoining buildings had pentrated the roofs and could not be seen. This effect was most marked where a bridge crossed a wide river. Towards the end of a raid, when the incendiaries had burnt out, the effect was reversed, the streets showing dark in contrast with the burning buildings between the streets.

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These fire mosaics were available far sooner after a raid than plottings by light tracks and they were utilised by the O.R.S. as qualitative evidence of where the attack fell, in interim reports on major raids - reports issued weeks before a detailed quantitative analysis could be made. Fire mosaics were also used extensively by R.E.8 in conjunction with damage plots, in assessing the effectiveness of incendiary weapons on behalf of the Air Ministry's 'Incendiary Panel'.

Plots of Marker Bombs

Analogous to the fire mosaics, but of even greater value in analysing raids, were the plots of target indicator bombs burning on the ground or cascading through the air. From early 1943 a large number of these plots were prepared by the A.C.I.U. ('N' Section); indeed most night raids and some day raids were dealt with in this way right to the end of the war in Europe. From October 1943 the introduction of colour film greatly assisted analysis by making it possible to assess the colour of at least a proportion of target indicators plotted. It would be difficult to over-emphasise the importance of these target indicator plots in raid analysis. Not only did they provide crucial evidence on how well the Pathfinders had centred the attack, but they also were invaluable in assessing the accuracy of various radar devices used in aiming the target indicators.

Analytical Methods

The data obtained from the various sources enumerated in the preceding section are susceptible of analysis in various ways. Thus, a rapid examination of the data which become available within a few days of the raid may reveal factors of operational importance which should be brought to the notice of all concerned as soon as possible. This examination is mainly of a qualitative kind, and any resulting numerical measures of success will be tentative. By the time all the data are available and the quantitative analysis is completed, the raid is operationally cold, and little immediate interest attaches to the results of analysis. This explains why so much of the detailed analysis undertaken has never been published. It, nevertheless, has great importance in long-term researches.

This present section will deal briefly with the methods of analysis used, classified for convenience as follows:-

(a) Methods of qualitative analysis.

(b) Methods of quantitative analysis.

(c) Methods of time analysis.

/Methods ......

Methods of Qualitative Analysis

For any given raid the data first available (within a very few days) were the Sortie Raid Reports and the Photographic Interpretation Section of Bomber Command Intelligence Branch plot of ground detail photographs. There was also the A.C.I.U. plot of target indicator bombs, and in some cases a fire mosaic; the raid reports yield, inter alia, a time-histogram of bombing, which depicts the raid extended in the time dimension, and the photographs illustrate its special distribution, though allowance has to be made for the non representative nature of these ground-detail photographs. One of the items included in the Sortie Raid Report is a brief narrative describing general conditions in the target area (originally provided by the captain; at the end of 1943 the air bomber was made responsible for this narrative on the grounds that he saw much more than the captain who was usually the pilot). In the case of key sorties, such as Pathfinders, much was learnt by reading these narratives in relation to the position of the aircraft at bombing in time and (if plotted) in space, relative to the rest of the raid. They are normally read in the first instance in time order, but if the plot of photos showed, e.g. a small subsidiary concentration of photos, then the narratives of the aircraft concerned would be collated.

This is a type of analysis about which it is very difficult to give a clear description. The methods are not mathematical but more akin to those of the law courts, or of the detective of fiction. A great number of strands of evidence are mentally assessed for reliability (mainly from their coherence and mutual consistency) and then woven together to form what is, in effect, a reconstruction of the raid. With rare exceptions, one is not faced by deliberately misleading statements in the Sortie Raid Reports, but cases are frequent in which the reporter is genuinely mistaken about what he saw or where he bombed.

From this prolonged process of analysis there gradually forms in the analyst's mind a more or less clear picture of the life-history of the raid. In the case of a raid which has fallen below expectation (and these are the raids mainly selected for study), the time when and reasons why it failed will usually emerge as analysis proceeds. For example, it might be that a small group of aircraft claim to have bombed a cluster of red target indicators at a time when it is known (from Pathfinder Force raid reports) that none were burning; one of these aircraft may have been plotted away from the main concentration and their descriptions of the target area may make it probable that the others were part of the same diversion. The evidence points to

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the use of decoy target indicators by the enemy. Moreover, this might be an isolated incident, limited in time to about ten minutes, or it might have the effect of attracting most of the rest of the raid, since, the decoy target indicator may have been 'backed up' in error by other Pathfinder Force aircraft dropping (say) green target indicators. (It should be explained that in most Pathfinder Force techniques certain crews acted as 'markers' dropping one colour target indicators which were placed on radar or visual identification of the aiming point, while other crews aimed at the 'markers' with target indicators of another colour to ensure that the aiming point for the Main Force was continuously marked).

Accuracy of Data

A prominent feature of this type of analysis is the varying accuracy of the available data. For reasons explained, the plotted position of the aircraft may in some cases be far from where the bombs actually fall. Times may be inaccurately recorded in the Sortie Raid Report, particularly when they are recollected subsequently instead of being noted down at the time. This inaccuracy is revealed when several aircraft report some outstanding phenomenon, such as a large explosion, in the target area; the recorded times will usually vary by two or three minutes each side of the mean time. Some raid reports tell a more consistent and coherent story than others; and in general a highly critical attitude of mind on the part of the analyst is essential.

Interim Reports

The results of this immediate analysis are to be found in a series of 71 interim reports issued as Bomber Command O.R.S. Reports, 'B' Series, on particular raids from 8/9 March 1942, to 12/13 August 1944, published for restricted distribution within the Command. Most of these were devoted to less successful raids, the results of which had plainly fallen below expectation, and made constructive recommendations designed to remove defects revealed by the analysis.

If these interim reports are examined it will be found that most of them are illustrated in two ways. There is usually a time-histogram of bombing and marking, showing by means of colours the proportion of main force aircraft bombing different types of markers. This is derived from the Table-Cloth described above. There is also in most cases a plot showing aircraft plotted by ground detail and also (from the fire mosaic) areas in which fires are burning. In some cases the raid is divided

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into two or three time periods with a separate plot, and always the different functional types of Pathfinder Force aircraft (blind illuminators, visual markers, backers-up etc.) are distinguished by different shapes of symbol. Each report is a tactical summary of the raid, necessarily giving prominence to the Pathfinder Force, and showing to what extent the plan of attack was successfully carried out.

In many of these interim reports an attempt was made to assess the proportion of aircraft bombing the target area, or within three miles of the aiming point. These estimates were based on the ground-detail plot, taking also into account the distribution of fires shown on the fire mosaic. As the plottings of aircraft by means of light tracks were not normally available when these interim reports were made, the estimates of success were necessarily tentative and less reliable than those appearing later in the final Night Raid Report.

Marshalling Yard Reports and Summaries

Of the same general nature as these interim reports on selected major raids is the series of reports covering the earlier attacks on railway marshalling yards in occupied territories in 1944. Issued about ten days after each attack, these reports were mainly concerned with analysing the accuracy and timing of pathfinder marker-aircraft, comparing the planned and achieved timing of the main force, and assessing the damage by counting craters seen within the yards on P.R.U. cover. On the last point, a certain density of bombing was theoretically required by the railway experts, and the reports gave the calculated density to be expected from the size of the bomb-load despatched and the density which was achieved. The first 15 attack (from Trappes marshalling yard, 6/7 March 1944 to Ghent marshalling yard (10/11 April, 1944), were reported on in this way and subsequently summarised in Report No. S.159 (1) and summaries were issued in respect of a further 23 attacks. This routine type of investigation was discontinued once the comparison between expectation and achievement had been adequately made.

Methods of Quantitative Analysis

In general terms, the requirement is to characterise any given raid by some numerical measurement of success, or by a set of such measurements, so that a whole series of raids carried out by one bombing technique can be compared with other series carried out by other techniques; also, so that seasonable and longer-term changes in accuracy and the varying effects of weather can be assessed.

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(1) 'Summary of 15 Oboe Groundmarking Attacks on Marshalling Yards, 6/7 March to 10/11 April 1944.' (A.H.B./IIH/241/22/14)

Nature of Bombfall Distribution

The bombfall distribution of any one raid, obtained either directly from a crater plot or indirectly from a plot of operational photographs, is made up of the superimposed bombsticks of individual aircraft. These will have bombed at different times throughout the course of the raid and at different locations within the overall distribution. For most raids the distribution of the individual aircraft in spece and time will not be entirely random; indeed, it is clear from the analysis of long and dispersed raids that successive mean points of impact (M.P.I.) of bombsticks, averaged over short intervals of time, usually show a systematic drift. The immediate reason for this is that the points of aim selected (target indicators usually) themselves changed during the course of the raid. The bombfall distribution of the raid as a whole is thus the aggregate of a pattern changing from minute to minute throughout the raid.

If a number of bombs are correctly aimed at a fixed aiming point, the resulting bombfall distribution will approximate closely to a definite form - the Normal or Gaussian distribution extended in two dimensions - centred upon the aiming point. The normal distribution is well understood mathematically and is therefore amenable to statistical analysis.

In the bombfall distribution of an operational raid, however, the M.P.I. does not usually coincide with the aiming point, if only because the point of aim is usually at a target indicator (or the M.P.I. of several target indicators) itself dropped with a certain error. Also, the distribution about the M.P.I. is not normal, if only because the point of aim has shifted throughout the raid. Finally, not all bombs will be 'correctly aimed'; gross errors will occur owing to such factors as defective bombs, bombsights, or bomb-release gear, or errors of judgement such as aiming at a decoy target indicator put down by the enemy.

Parameters of Bombfall Distribution

This complex situation can best be dealt with if the following steps can be taken:-

(a) The gross errors can be recognised and eliminated.

(b) The M.P.I. of the residual distribution can be found.

(c) The scatter about the M.P.I. can be measured.

This process will lead to three fundamental measurements (or parameters) which collectively will adequately describe the raid as a whole, as follows:-

(a) Proportion of gross errors.

(b) Systematic error (position of M.P.I. relative to aiming point).

(c) Radial error about M.P.I.

/Gross Errors

Gross Errors

The recognition and elimination of gross errors has been found in practice to be rather a different problem in the case of crater plots from which it is in the case of photo plots. In the latter case the recognition of any but the most obvious gross errors is a difficult problem which was not satisfactorily solved until late in the war. The whole question is discussed in two reports, Bomber Command O.R.S. Report No. 127 [1] dealing with circular and Bomber Command O.R.S. Report No. 137 [2] with elliptical distributions. Briefly, the adopted method consists in using the whole sample (apart from blatant errors) to determine the M.P.I. and the standard deviation. A multiple of the latter is then used as radius in a circular distribution, or as semi-diameter in an elliptical distribution, and all points lying outside this circle or ellipse are discarded. The process is repeated on the residue, yielding a smaller standard deviation and therefore a smaller circle or ellipse, with the possibility of further discards. After a few repetitions the standard deviation closely approaches a minimum value (which is multiplied by a constant to give the true value required as a measure of scatter).

In large and roughly symetrical distributions the effect of eliminations on the position of the M.P.I. can be neglected, with consequent economy in computation. Small or irregular distributions are more troublesome, particularly if elliptical, when elimination may also seriously affect the orientation of the ellipse.

In the case of crater plots, it has been found satisfactory to eliminate gross errors by eye in the first instance, with a subsequent check on the accuracy of this process by making frequency diagrams of the residual distribution and fitting normal curves to them. In a photo-plot each point represents the centre of a stick of bombs; in a crater plot this point is replaced by a cluster of individual bomb-craters. The effect of this is to bring into sharper relief any discontinuities in the distribution, and the gross errors stand out with increased clearness.

Systematic Error

The systematic error has been taken as the distance separating the M.P.I. of bombs from the aiming point, measured in the form of distance and bearing (radially) or of two components at right angles (e.g. line and range), depending on the requirement. As a bare parameter, descriptive of the distribution this is adequate. But if the size of the systematic error is such as to call for explanation, or if the accuracy of bombing is under examination, it becomes necessary to consider the points of aim rather than the briefed aiming point.

/From

(1) Determination of the Root Mean Square Deviation and the Elimination of Gross Errors from Circular Distributions. (A.H.B./IIM/a1/6a, Oct. 1945).

(2) The Rejection of Gross Errors in Elliptical Distributions. (A.H.B./II/39/1).

From the plot of target indicators or other pyrotechnic markers, along with the evidence of qualitative raid analysis, it is possible to decide with fair accuracy which markers were effective, i.e. taken into account by the air bombers. The M.P.I. of bombs can then be related to the M.P.I. of effective markers (systematic bombing error), and the latter to the aiming point (marking error). It must be stressed that this is an approximation to the true situation. Throughout any raid the number and relative positions of markers are changing and it is rarely possible to ascertain for any one aircraft exactly what was the point of aim. Thus, the M.P.I. of all true points of aim cannot be found, and the M.P.I. of effective markers is used as an approximation.

Random Error

The scatter of bomb craters or plotted aircraft about their M.P.I. has usually been measured by the radial standard error (standard deviation) and quoted in that form, or as two component linear standard deviations along axes at right angles, or in the alternative form of radial average error or radial probable error. The probable radial average error was more acceptable to the Air Staff, and the probable error was useful for drawing 50 per cent circles or ellipses. With very few exceptions, in all the published work of the O.R.S. 'radial average error' means in fact the radial standard error multiplied by 0.8862, and in diagrams showing a 50 per cent circle its radius has been taken as 0.8326 times the same standard error.

While a case could be argued for giving the actual arithmetical mean error, and for drawing a true 50 per cent circle by counting outwards from the M.P.I., particularly when dealing with distributions which are not strictly Gaussian, the work on quantitative raid analysis has in fact been based throughout on Gaussian theory. Thus, although crater plots and photo-plots may not be strictly Gaussian, whether circular or elliptical, they approximate to that form in varying degrees and, by assuming that it applies, a whole analytical apparatus is to hand for tests of significance and for the elaboration of forward planning methods.

Procedure

The methods of calculating the M.P.I. and radial standard error have been described for photo-plot analysis in Bomber Command O.R.S. Report No. 124 [1] where a partially worked example is illustrated. Briefly, it may be said that both photo and crater plots have been dealt with by analysing the two-dimensional distribution into two

/linear

(1) 'The Technique of Raid Analysis and Forward Planning.' (A.H.B./II/39/1).

linear components at right angles, and by grouping the data in frequency-bands of convenient width. Thus, a Cartesian grid of squares is superimposed on the plot, the orientation of which has varied in different cases. For 1943 photo distributions which were markedly elliptical, the grid was orientated along and across the ellipse. Later photo distributions, which were mostly circular, were analysed along and across the line of approach to the target, and crater plots along and across the mean heading of bomb sticks. The grid squares have also varied in size, measuring one mile for earlier photo plots, usually 300 yards for later photo plots, and usually 100 yards for crater plots. The two sets of marginal totals yield the co-ordinates of the M.P.I. and also (from second moments about the means) two linear standard deviations, S_x and S_y. The radial standard error, S_r, is obtained from standard deviations, S_x and S_y. The radial error S_r, is obtained from

$$(S_r)^2 = (S_x)^2 + (S_y)^2$$

In the case of most crater plots a (linear) frequency histogram has been drawn from the marginal totals and compared with a fitted Gaussian curve as a test of normality.

This procedure involves a considerable amount of arithmetic and the volume of work which the O.R.S. was able to accomplish on the quantitative analysis of crater plots and plots of night photographs was only made possible by the use of electric calculating machines. These were also of great use in many other investigations and must be regarded as one of the essential tools of an Operational Research Section.

Incomplete Crater Plots

As explained on page 33, a crater plot is sometimes incomplete through the P.R.U. cover not extending far enough. In analysing such a crater plot it is usually necessary to estimate the number of aircraft whose bombs fall outside the area of the crater plot. This is done by a careful comparison of the crater plot with the plot of operational photos which, of course, is not limited in this way. Late in the war when most operational photos were plotted and raids were well centred. this comparison was necessary only for detecting additional gross errors not included in the crater plot.

Crater plots may also be incomplete, in spite of adequate P.R.U. cover, where bodies of water intersect the distribution. If the central part of the distribution is over water, the estimation of the missing craters becomes so difficult as to make an analysis scarcely worthwhile,

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especially if an alternative photo plot exists; in other cases it is usually possible to analyse a large sector of the distribution, say a semi-circle or more, and to estimate the remainder by angular proportion.

Other Parameters

The three parameters described on page 39 are necessary to detailed forward planning. For mere descriptive purposes less elaborate parameters are possible. Thus, the proportion of aircraft reporting attack which bombed within a given distance of the aiming point is a useful parameter, which is compounded of radial and systematic errors. The distance chosen should bear some relation to the degree of scatter and will therefore decrease with increasing accuracy of bombing; down to August 1942, the proportion of photos plotted within five miles of the aiming point was used, but thereafter the radius was three miles, except for very small targets when one mile was used. Similarly, for some 200 crater plots of precision targets a 20 acre circle (radius 175 yards) was used (see page 39).

Percentage within three miles

During the period from August 1942 until January 1944, the percentage of aircraft bombing within three miles of the aiming point was widely employed as a parameter at all stages of analysis from the 'Summary of Night Photographs', issued with the plot of ground-detail photos on the morning after the raid by the Photographic Interpretation Section of the Intelligence branch at Headquarters, Bomber Command to the final 'Night Raid Report', prepared by the O.R.S. and issued by the Command some months later. The immediate 'Summary' could not be expected to provide a very firm estimate, and the O.R.S. was able to show in July 1943 that it had been systematically pessimistic for some months, largely owing to the method by which the percentage was calculated. The method was to express the number of G.D. (ground-detail) photos plotted within three miles as a percentage of all ground-detail photos, whether plotted or not, and thus assuming that all unplotted G.D. photos were outside three miles. This last assumption was probably sound in the earlier days of small and scattered raids, but by 1943 a considerable proportion of photos showed mainly a confused mass of light tracks, and of ground detail the merest trace or none at all. Most of those showing only a trace of ground-detail were not easily plottable and were therefore automatically assumed to be outside three miles, whereas, except in a badly centred raid, the light tracks would, however, suggest the contrary. Bomber Command O.R.S. Memo No. M96 (1) suggested excluding from the category 'ground detail' all photos which were mainly covered in light tracks, and showed that if this were done

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(1) 'Immediate Estimate of Percentage of Aircraft Reporting Attack which bombed within three miles, July 1943'. (A.H.B./IIH/241/22/3).

for 12 large raids which took place from April to July 1943, the new percentages were more closely in agreement with the better estimate given in the final Night Raid Report, in which due weight was given to later plottings by light tracks.

The same point was investigated in more detail in the case of the raid on Wuppertal (Barmen) on 29/30 May 1943. In this case the photos unplotted by either ground-detail or light tracks were carefully examined, and assessed as inside or outside three miles on the basis of what they showed. This analysis, described in Bomber Command O.R.S. Report No. M.97,(1) yielded a maximum and minumum value depending on whether or not the unplotted photos were included in the denominator of the percentage; the arithmetical mean of these two values was taken to be the final estimate.

Further analysis of 21 raids, involving the assessment of unplotted photos as well as plottings by ground detail and by light tracks (16 of which raids are reported on in Bomber Command Memo. No. M.149)(2) showed that when this arithmetic mean was based on the plotted sample (i.e. without assessment of the unplotted photos) it still tended to be pessimistic. Averaged over the 21 raids, the best value was found to lie in 75 per cent of the range from the minimum to the maximum value. Amended 3/4-range values for the 21 raids were issued as an appendix to the Night Raid Report No. 476 (3) with an explanatory note. On the average the mean percentage had been 5.6 per cent too low, and at its worst 10 per cent too low.

Point Densities

The obvious disadvantage of expressing raid success in terms of proportion of aircraft bombing within a selected distance of the aiming point is that parameters relative to one radius are not comparable with those relative to another, and that one cannot be calculated from another owing to the varying systematic errors. Moreoever, as the circles become smaller, the random heterogeneous nature of the distribution increasingly disturbs the result. Thus, two distributions with exactly the same parameters might have widely different proportions of actual bomb-craters within 175 yards of the aiming point. This difficulty can be obviated by the following device. The actual distribution is replaced by a theoretical normal distribution of the same parameters, the reference circle is reduced to the limit where it becomes a point (the aiming point) and the parameter is given in the form of a density at the aiming point either

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(1) "The Estimation from Night Photographs of the proportion of Aircraft attacking the Target", 5 August 1943. (A.H.B./IIH/241/22/3).

(2) The Nature and Use of the Photographic Sample in Night Operations.

(3) A.H.B./II/39/1/3

absolute (e.g. strikes per acre) or relative (e.g. strikes per acre per 1,000 bombs aimed). This parameter can be used however great or small the scatter may be, and is not affected by the heterogeneity of the distribution; it has the further great advantage that all the plotted points within the normal distribution are used in calculating the density.

A similar point-density can be given for the M.P.I. instead of the aiming point. In its relative form (per 1,000 bombs aimed) it becomes an alternative form of the radial standard error; in the form 'per 1,000 bombs dropped' it takes into account gross errors, and in the form 'per 1,000 bombs despatched' it takes also into account abortive sorties. Point densities, M.P.I. or aiming point in one or other of these relative forms are useful single-number paramaters.

Percentage within Target Area

In November 1943 the results of raids given in the Intelligence (Photographic) Interpretation plot were related to the zoned target area instead of to a three mile circle, and a corresponding change was made in the Night Raid Report, as explained in an appendix to Night Raid Report No. 476.[1] This is a parameter of a totally different kind and, since it is relative to the size and shape of the target, it measures potential effectiveness rather than accuracy. It cannot be used for comparing bombing techniques except in the rare case of different techniques used on the same target.

Critique of Procedures: Linear Components

It is theoretically possible to construct a distribution such that the range and line linear components are strictly Gaussian, but the actual radial distribution not so. Thus, consider a true Gaussian radial distribution in the form of a Cartesian grid of cell frequencies, with marginal totals forming two linear Gaussian distributions; the cell frequencies can be changed in numerous ways in both position and magnitude so as to give non-Gaussian distributions, without disturbing the marginal totals. It follows that tests of normality applied to the marginal totals do not guarantee normality in the radial distribution.

Any radial distribution can be (and has been) tested for normality by comparing observed with expected frequencies in a sample of annuli, annular sectors or squares eccentric to the distribution, using the chi-squared test. This is troublesome if the analysis is proceeding in any case by linear components; it would be less so if direct radial analysis was used. There is,

(1) A.H.B./II/39/1/3.

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however, no adequate analytical apparatus for two-dimensional distributions; in particular, in small-sample theory there are as yet no satisfactory analogues to Fisher's 'z' and 'Student's' 't' distributions. It is therefore considered that the method of linear components is the only satisfactory one. It is useful for quickly finding the M.P.I. and, by a variance-ratio test, for quickly finding the M.P.I. and, by a variance-ratio test, for determining significant ellipticity; in elliptical distributions it is essential. Doubts as to its justifiability rest on the non-Gaussian nature of many distributions, particularly photo plots.

Critique of Procedure & Gaussian Assumption

Single bombs correctly aimed at a fixed aiming point should result in a Gaussian distribution of craters; so also should bombs correctly aimed when each aircraft has its own point of aim, provided the latter are themselves normally distributed. Operationally, when target marking of the type employed by the Pathfinder Force is used, the difficulty arises in that the points of aim are not normally distributed but tend to cluster round different effective target markers at different periods of a raid. Thus, instead of the pre-requisite of normality, namely a large number of negligibly small sources of error, there is a small number of large sources of error, and the resulting distribution of craters or photos is not Gaussian.

That this is so has been proved by superimposing a number of non-Gaussian photo-plots by M.P.I.and line of approach (either geometrically by literal superimposition or arithmetically by adding frequencies and squares). The aggregate distribution so compounded increasingly approximates to normality as more plots are added.

Considering all things, practical simplicity in computation so that junior staff can apply the method, availability of an adequate analytical apparatus, and (above all) the permissible tolerance in raid parameters in view of the (in any case) large variations from raid to raid, it is held that the analytical methods here described are satisfactory.

Shape of Bombfall Distributions

Bombfall distributions as seen in a crater plot tend to be slightly elliptical, particularly if there are few bombs; it is more extended along the mean track than across it. This is mainly because bombs are dropped in long sticks which are not random in direction but cluster round the mean direction, but partly because the actual bomb-aimer's error often tends to be greater in range than in line. For

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any given crater plot, the corresponding photo plot is more extended in line and, indeed, in the last years of the war was usually not significantly elliptical at all. The reason for this is twofold; first, the effect of stick dispersion is ncessarily absent from the photo plot, and, secondly, the effect of photo-dispersion is to increase the apparent scatter in line more than it does in range. This is because at the moment of photography the aircraft is seldom level and and amount of lateral bank is inherently likely to exceed that of fore-and-aft tilt.

Photo Dispersion

This whole matter is discussed in Bomber Command O.R.S. Report No. 136 [(1)] which gives correction factors for photo-dispersion, depending on height, separately in line and range, and, alternatively compounded in radial form. The dispersion factors were worked out from a compounding and smoothing of operational data from several raids in which plots of bombing frames could be compared with plots (from the same raids) compiled by forward plotting from the release point frames. As such, the correction factors apply to the non-existent 'average raid' and whilst they can be safely applied to a set of average parameters, they should not be uncritically used for a single raid. Indeed, there are cases where the tabulated photo-dispersion has been greater than that of observed bombing frames, so that the residual corrected dispersion has been meainglessly negative.

Method of Time Analysis

The method of raid analysis used by the O.R.S. since early 1943 is given in Bomber Command O.R.S. Memo No. M.149 [(2)] This memorandum describes the method by which further information is extracted from night photographs by 'assessing' the unplotted residue, and the analysis of the raid in five minute periods. In this way the drift of the M.P.I. during the course of the raid could be followed. In some cases it shifted slowly and in others rapidly; sometimes it was merely a 'random walk' and sometimes a definite trend. The scatter of each five-minute distribution about its M.P.I. was also investigated.

From its title, 'The Nature and Use of the Photographic Sample in Night Operations', will be seen that the memorandum was mainly concerned with photographic questions, such as the bias of the ground detail sample both in space and in time. But the method was devised and used to deal with tactical questions of raid structure and dynamics, and to compare different marking techniques in detail.

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(1) 'The Measurement of Concentration of Bombing from Photographic Plots.' (A.H.B./II H/258/1/290 B).

(2) 'The Nature and Use of the Photographic Sample in Night Operations.'

A series of reports giving the detailed time-analysis of individual raids to be followed by an exhaustive summary, was projected. The process of analysis is very time-consuming, however, and the project was not realised. Plots and graphical summaries for 17 large 1943 raids are nevertheless presented, as bare data illustrative of a most useful technique, in Bomber Command O.R.S. Memo No. M. 148.(1)

Results of Analysis

The sources of data and method of analysis having been described above, a brief indication follows of the way in which the results so obtained were used.

Results of Qualitative Analysis

The object of this form of analysis being the rapid estimation of tactical success, with reasons for relative failure of operations and recommendations for avoiding similar failure in the future and for improvements, its results were mostly published as soon as possible in the form of reports in the 'B' series. These were restricted in distribution to Headquarters Bomber Command and the Air Officers Commanding Groups participating in the operation concerned. Since they were issued quickly, were of obvious practical importance, and made concrete suggestions for improving future operations, they were in general welcomed in the Command. There were, of course, cases where the report was critical of some detail in planning, and the findings were normally referred to the Air Officer Commanding the Pathfinder Force for comment prior to issue. It must be mentioned that sometimes the results of these investigations merely confirmed what had been discovered previously by the more superficial study made directly after the operation by Headquarters, Pathfinder Force.

Results of Quantitative Analysis

By contrast with the former, the results of quantitative analysis appeared to be somewhat academic and unpractical. A long process of analysis issued in a set of numerical parameters, which are merely descriptive of the raid in question. There was, therefore, no occasion for publishing them. The fact is, however, that raid parameters, which are the end-product of the process of quantitative analysis, become in turn the raw data for further researches. By collecting the parameters for whole groups of comparable raids, it became possible to characterise the group as a whole in a reasonably exact way, and thence to compare one group with another. Thus, the way was open to assessing and comparing different bombing techniques,

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(1) 'The Development in Time of 17 Raids on German Towns in 1943.'

to furnish precise information on the accuracy of Bomber Command attacks under given conditions, and to estimating the weight of attack required in future operations.

The work of quantitative raid analysis was therefore carried on. The parameters had to be calculated continually due to the continual improvement in the success, in terms of aircraft bombing the aiming point of Bomber Command's operations. The data obtained was used in the estimation of force requirements when the bomber effort was turned on to the attack of multiple targets preceding the landings in Normandy and thereafter in the campaign against communications and in attacks in support of the ground battle.

A set of 82 finished photo plots, on transparent linen, at a scale of 1:25,000 showing target outline, plotted aircraft, plotted markers bombs, and (where applicable) the M.P.I. of plotted aircraft and the calculated 50 per cent circle or ellipse about it, was filed with Bomber Command O.R.S. These all refer to raids carried out in the last year of the war. For raids from 4/5 September 1942 to 4/5 December 1944, plots on a scale of one inch to one mile, including all ground detail plottings and plottings by light tracks were also prepared and issued as part of the Bomber Command Final Reports on Night Operations which were prepared by the O.R.S.

CHAPTER 3

THE STUDY OF NIGHT BOMBING TECHNIQUES

Introduction

In these days of radar aids to navigation and highly developed marking techniques it is difficult to form an adequate conception of the difficulties which confronted bomber crews' attempts at raiding enemy targets at night at the time the O.R.S. was formed. The only aids available to the navigator-cum-bomb-aimer were compass, map, loop and sextant, combined with such visual identification of ground detail as he was able to make by starlight, moonlight, or in the light of an occasional unshaded flare. The problem in these days was not only one of navigating to the target area, but having performed this task, the navigator was then faced with the still more difficult, though most important, part of his mission, namely that of getting a visual fix, either of the target itself or of some clearly identifiable landmark within a few miles of the aiming point from which a dead reckoning run could be made. This process of searching for the target commonly occupied from 20 to 40 minutes, and was sometimes continued for more than an hour in the face of intensive anti-aircraft fire and, bearing in mind these conditions, it is easy to understand the lack of success which attended many of our night raids in the early stages of the war.

Early Raid Analysis

A few days after the formation of the O.R.S., Bomber Command carried out an attack against the important synthetic rubber plant at Huls (6/7 September 1941). Crews reports were very encouraging but subsequent photographic reconnaissance revealed no damage at all to the target, and the Commander-in-Chief asked the O.R.S. to investigate. The analysis made (1), the first of its type, served to demonstrate the magnitude and importance of the problems involved. On this occasion 45 sorties were despatched, but judging from the photographs taken by seven aircraft the closest to the target was six miles from the aiming point. It was subsequently found that the force attacked an elaborate decoy installation ten miles from the target. The results of this investigation owing to the scanty nature of the evidence, did not throw much light on the reason for failure, but showed the need for further study of the results of attacks in various weather conditions and on targets of various types. They also stressed the urgent need for a much higher proportion of camera carrying sorties in order that more complete information on the distribution of bombing might be obtained.

Three raids on the Baltic port of Stettin in September 1941 provided material for further analyses which, as in the case of the Huls raid, were based on night photographs and on information supplied on the night photographic plotting forms and special interrogation reports. In addition, the navigator's logs were examined. As already stated, the actual work of

(1) 'Investigation of Raid on Huls, Night of 6/7 September 1941.' ~~Bomber Command O.R.S. Report~~ No. S.3.

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interpreting and plotting the night photographs was done by 'N' Section of the Central Interpretation Unit. The Stettin raids were instructive because one of them, that of 30 September/1 October, was remarkably successful, judged even by the high standard reached later, 80 per cent of the photographs being plotted within two miles of the aiming point, whereas on the other two occasions very few of the crews were succesful in finding the target, though most of them navigated successfully to the target area.(1) The difference in the condition of the moon on the three nights was shown to be the chief factor for the variation in success, though fires, probably decoys, in open country to the northwest of the city, were an important subsidiary cause of failure on two occasions. The investigations also demonstrated the inherent unreliability of crews' reports and the danger of basing any conclusions as to the success of the attack on these alone. Thus, of the unsuccessful photographs confidently claimed to have been taken over the centre of Stettin during the three raids, about 70 per cent were plotted more than four miles from the centre of the city, several being twice or three times that distance.

The general experience gained as a result of these early raid analyses emphasised that the difficulties involved in navigating to the target area, great as they were, were relatively small compared with the difficulty of identifying the target itself, especially on dark nights, and enabled the many problems involved to be clearly formulated. The whole question of target identification was discussed at an informal meeting called by the O.R.S. at Headquarters Bomber Command on 6 December 1941, which was attended by representatives of the M.A.P. and the Royal Aircraft Establishment, and the lines along which it was considered that future research and development should be conducted were incorporated in O.R.S. Memo No. 88.(2) Among the recommendations made in this report was one to the effect that consideration should be given to 'the formation of specialist squadrons to initiate raids and to raise fires', which appears to be the first reference to the possibility of a special Pathfinding Force such as was eventually instituted in August of the following year. Another recommendation stressed the need for the 'use of reconnaissance flares by a number of aircraft in co-operation', a technique which formed the basis of nearly all the target marking methods subsequently developed.

The O.R.S. investigations into the problem of target identification at night fell under the following three headings:—

(a) Extensive analyses of night photographic evidence to determine under what conditions the greatest success was likely to be achieved, and what type of landmarks were most suitable for visual identification.

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(1) 'Analysis of Night Raids on Stettin, September 1941'. Bomber Command O.R.S. Memo. No. 89 dated 23 April 1942. (A.H.B./IIH/241/22/3).

(2) 'The Success of Night Bombing Attacks, An Appreciation.' Bomber Command O.R.S. Memo. No. 88 dated 22 December 1941. (A.H.B./IIH/241/22/3).

/ (b)

(b) Investigation of possible aids to visual identification which might be of immediate operational application.

(c) Longer term research on problems of visual identification of ground features at night.

As regards the first heading, an additional question was added to the night Photographic Plotting form, which dealt with the location of the area photographed. This was:-

(a) What place do you think you photographed?

(b) Did you recognise the place photographed?

(c) How did you recognise it?

The first answers to these questions were obtained on the night of 20/21 October 1941, and at the end of the month a preliminary review of the first 209 forms returned was made.[1] As only 34 of the 79 crews who claimed to have identified the target returned successful photographs, the evidence was considered insufficient on which to base firm conclusions and it was decided to extend the analysis to cover the period from October to December 1941.

The results of the wider investigation[2] showed clearly the need for crews whenever possible to use more than one feature to identify the target. Thus, of the crews who claimed to have identified only a single ground feature, it was estimated from photographic evidence that only 33 per cent successfully located the target, compared with 47 per cent for those who used two features, and 82 per cent for those who used more than two. In addition there was found to be a big difference in the reliability of various ground features for visual fixing, lakes and rivers, which were the most popular with crews, proving the least reliable, and coastal features, especially docks, the most trustworthy. This report, which was circulated to all Bomber Command stations, emphasised the need for a general improvement in the standards of map-reading, and for practical experience of its use in flights at operational heights during the period of training. Unfortunately at this period it was not possible to carry out the latter proposal as, owing to G.A.F. activity over this country, training flights had to be carried out below a ceiling of 7,000 feet. It was not until late in 1942 that this restriction was removed.

Importance of Visual Identification

It was assumed that the introduction of the long-awaited radio aids would not provide the complete answer to all the problems of navigation and target finding, particularly on the longer range targets, and that visual identification of ground features would continue to form an integral part of our night bombing techniques, if only because it was the one method of identification

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(1) 'Preliminary Note on Questionnaire relating to Target Identification.' Bomber Command O.R.S. Report No. S.19. (A.H.B./IIH/241/22/14).

(2) 'Statistical Evidence on the visual location of targets by night.' Bomber Command O.R.S. Report No. S.31. (A.H.B./IIH/241/22/14).

least subject to enemy interference. This assumption was later proved by the course of events to have been completely justified, for although the task of visual identification subsequently became relegated to specialised crews, it remained until the end of the war the basis of most of the target marking techniques used on targets beyond the range of Oboe or Gee-H. It was therefore decided, at the end of 1941, to proceed with a more extensive survey of all the factors which might possibly have a bearing on the problem, such as the use of night glasses, the most suitable type of flares for illumination, possible modifications in aircraft design which might assist visual identification, the desirability of special training at night vision and the lines along which such training should be conducted. The scope of the investigations and the progress made is discussed in a later chapter.[1]

The Use of Gee as a Target Identification and Bombing Device

As a result of the experience in night bombing gained in 1941, it was abundantly clear that, except under clear moonlight conditions, little success could be expected with the methods then in use, and that although the use of binoculars and flares of improved types and increased training in night vision might, in the course of time, bring about some improvement, no marked advance could be expected until the introduction of radio aids which would make successful night raiding less dependent on visual identification of ground features. The first such device to be used in Bomber Command was TR1335, later known as Gee, which was developed by T.R.E. and first used operationally on the Essen raid on 8/9 March 1942.

The Gee system, which is based on the measurement in the aircraft of the phase difference between signals transmitted from three different ground stations, was primarily designed as an accurate navigational aid, whose object was to enable large numbers of aircraft to navigate with certainty to targets in Germany, particularly in the Ruhr area where most of the heavy industries were situated and which presented the greatest difficulty from the point of view of visual identification. With this in mind the first chain (the Eastern Chain) was established with its maximum accuracy (for a given range) over the Ruhr.

Methods of Using Gee

Several months before Gee came into operational use, the O.R.S. issued a report[2] summarising the operational facilities which it could be expected to provide, and putting forward some possible tactical uses of the device. In view of the fact that the operational range of Gee might be limited after a comparatively short time by enemy jamming, and the consequent necessity of exploiting the device to the full from the beginning, it was suggested by the O.R.S. that research should be carried out before Gee was brought into operational use in order to determine the best methods of using

(1) See Chapter 9.

(2) 'Operational Use of Gee.' Bomber Command O.R.S. Report S.23. (A.M. Science 1 Library).

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the equipment. In a subsequent report (No. S26)[1] further details of the type of experiments which should be carried out by the recently formed 'Gee Development Flight' were given.

As the result of this report, a meeting was called by the Commander-in-Chief on 17 January 1942 between representatives of the Air Staff and the O.R.S., to discuss the whole question of the operational use of Gee. It was agreed that, of the two main types of operation viz:-

(a) Operations led by Gee aircraft,

(b) Those carried out by Gee aircraft only (blind bombing),

Type (b), in view of the limited number of Gee aircraft which would be available at first, should be used under poor weather conditions, when it was unlikely that other bombers would be able to find the target, even if assisted by Gee aircraft. With regard to operations of type (a), the three possible methods by which the Gee aircraft could lead the whole force to the target were considered, viz:-

(i) The Gee aircraft to act as fire raisers. Non-equipped aircraft to bomb the fires.

(ii) Gee aircraft to drop flares to illuminate target and thereby enable the remainder of force to bomb visually.

(iii) Formation attacks led by Gee aircraft.

Owing to the tactical difficulties associated with formation flying at night, method (iii) was not thought to be practicable. Methods (i) and (ii), however, were subsequently adopted and formed the basis of the Samson and Shaker techniques used during 1942. It was agreed at the meeting that experiments should be carried out in order to develop a method of collaboration between the flare dropping aircraft equipped with Gee and the 'Follower' aircraft not so equipped. The O.R.S. was entrusted with the task of drawing up detailed plans for such experiments.

Flare Dropping Experiments

The Isle of Man was chosen as a suitable target for the experiments, because the accuracy of Gee in that area was approximately the same as its accuracy over the Ruhr. According to the plan originally put forward by the O.R.S.[2], a force of Gee aircraft were to arrive over the target at zero hour and, after dropping one flare each, were to orbit and make a second run, attempting to identify the target visually and at the same time dropping another flare. Altogether six such orbits were to be made, thereby keeping the target illuminated for a period of about 20 minutes. The object of these flares was two-fold, namely to provide a beacon to guide the non-equipped aircraft to the target, and to illuminate the target, thus making visual bombing possible. The non-equipped aircraft were also to drop one

(1) 'Operational Use of Gee - II.' Bomber Command O.R.S. Report No. S.26. (A.H.B./II/69/210)

(2) 'Operational Use of Gee - III. The Use of Flares in conjunction with Gee.' Bomber Command O.R.S. Report No. S.30. (A.M. Science I Library)

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flare each in the area where the other flares were burning. The plan of the exercise, known by the code word Crackers, was later extended to include the use of flare sticks for illumination and to test the value of coloured flares and searcher flares. In order to get the maximum amount of information out of the exercise a detailed questionnaire was drawn up, to be completed by pilots and observers at interrogation. The O.R.S. also sent a ground observer to the Isle of Man.

The first exercise, which took place on the night of 13 February 1942, was rather spoilt by a ground station fault which resulted in the flares being laid in two groups, several miles apart, and by a very high wind. It did, however, serve to establish that the illumination provided by single flares dropped on Gee at the rate of 12 every three minutes, although satisfactory as a beacon for attracting the main force to the target area, was quite inadequate for visual identification of the target. Sticks of flares consisting of six bundles of three flares spaced one mile apart, however, gave excellent results, and it was accordingly decided to organise a further exercise, Crackers II, to test more fully this method of flare dropping and to decide on the best number of flares and stick spacing to use.

The railway station at Brynkir (North Wales) was the 'target' for this second exercise, which took place on the night of 19/20 February under cloudless but somewhat hazy conditions. This exercise was fully successful and on the basis of the results the O.R.S. working in conjunction with No. 3 Group were able to put forward a detailed plan for illuminating a target for a period of 15 minutes with successive waves of Gee aircraft, each carrying 12 bundles of three flares to be dropped at ten second intervals.(1) In the light of these flares an incendiary force would then attack between Z and Z plus 15 lighting up the target for the main striking force, who would bomb the fires.

<u>Attacks on Essen Using Gee</u>

The above plan, which formed the basis of the technique known by the code word Shaker, was first put into operation on the night of 8/9 March 1942. The target was Essen, and high hopes were held that a really heavy blow would at last be struck at this most important but very difficult target. A force of 211 aircraft was despatched, including 74 equipped with Gee, and weather over the target was good apart from the usual ground haze. The raid lasted for two hours ten minutes, but the results were disappointing, and post raid cover revealed no damage to the main target area, though a few aircraft were shown by their night photographs to have bombed the southern outskirts of the town. An O.R.S. analysis of this raid (~~Report B101~~ No.) showed that, although the flare laying was on the whole satisfactory, many of the incendiary force did not arrive until the flares were out and scattered their loads over a wide area, mostly short of the target, thereby attracting other aircraft.(2)

(1) Letter from No. 3 Group H.Q., Reference 3G/S2176/2/Ops dated 20 Feb.1942.

(2) 'Attack on Essen, 8/9 March 1942, using T.R.1335'. Bomber Command O.R.S. Report No. B.101. (A.H.B./IIH/241/22/12).

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Within the course of the next three months, eleven further major operations using Gee were carried out against Essen, including one of 956 aircraft, but daylight reconnaissance indicated that no major damage had been inflicted either on Krupp's works or on Essen town, and it became clear that the difficulties of the new method of attack had been seriously under-estimated. On most of these raids the original Shaker technique, with minor variations in timing, was employed; but on 10/11 March flares were not used, the Gee aircraft dropping 250 pound incendiaries blindly to act as a beacon for the Main Force. This was the first operation of the Samson type, which was used in preference to Shaker when it was thought that weather conditions over the target would not be good enough for visual identification.

Detailed analyses of all these early Gee operations were carried out by the O.R.S. in order to try and discover the causes of failure, as a preliminary to suggesting remedial measures. A number of these were published as reports in the 'B' Series, and a general summary of the first ~~10~~ ten operations ~~which~~ was written.(1) ~~be found in Report B111~~ ~~(1)~~ and in a report entitled 'Note on Attack on Essen' which was written by the O.R.S. and issued by the Air Staff for distribution to all Bomber Command stations. At the same time investigations were carried out into the operational accuracy of Gee, based on the plotted positions of the photographs taken by aircraft which were known from their sortie raid reports to have bombed blindly.

Although the accuracy of Gee in the Ruhr and Rhineland was found to be more than three times worse than that achieved by expert crews of No. 1418 Flight over this country, the 50 per cent zone being about five miles in radius,(2) ~~(Report No. S47)~~ ~~(2)~~ it was clear that this alone was not responsible for the failure to hit Essen. Moreover, Gee operations against other cities such as Cologne(3) ~~(Reports B105, B108, S44, B110)~~ (4) (5) (6) had achieved considerably greater success, and it was concluded that the relative lack of success on Essen was due in a large measure to the peculiar situation of that target; in particular, the lack of any clearly recognisable landmarks in the near vicinity and the proximity of many other industrial towns of similar size, made Essen a very difficult target for any method of attack, such as the Shaker technique, which depended on visual identification. Even when the Gee aircraft succeeded in laying an adequate concentration of flares, the ever present industrial haze so scattered the light that visual identification of the ground was very difficult. As a result, the incendiary force on two occasions attacked the wrong town, viz Hamborn on 9/10 March and Schwelm on 12/13 April. Furthermore, the fact that the main striking force, which was not equipped with Gee, was instructed to bomb on the fires started by previous aircraft made them very vulnerable to enemy decoy activity, and, on two raids during March 1942 a

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(1) 'Attack on Essen. Blind Bombing by T.R. 1335.' Bomber Command O.R.S. Report No. B.111. (A.H.B./IIH/241/22/12).

(2) 'Operational Accuracy of Blind Bombing with T.R.1335, March-April 1942.' Bomber Command O.R.S. Report No. S.47. (A.H.B./II/69/157).

(3) 'Attack on Cologne, 13/14 March 1942.' Bomber Command O.R.S. Report B.105. (A.H.B./IIH/241/22/12).

'Attack on Cologne, 5/6 March 1942.' Bomber Command O.R.S. Report B.108. (A.H.B./IIH/241/22/12).

'Blind Bombing Attack on Cologne, 22/23 April 1942.' Bomber Command O.R.S. Report No. S.44. (A.H.B./II/69/157).

'Attack on Cologne, 27/28 April 1942.' Bomber Command O.R.S. Report No. B.110. (A.H.B./IIH/241/22/12).

large proportion of the force was in fact diverted by decoy fire sites at Rheinberg, some 20 miles west-north-west of Essen.

The Samson technique, which was used on the night of 10/11 March was no more successful. Apart from the poor timing of the Gee aircraft, the 250 pound incendiaries which they dropped were quite insufficient to provide a beacon for the main striking force.[1] There was clearly a need for a far more distinctive type of marker bomb if operations of this type were to be carried out successfully.

Major Gee attacks on other targets carried out during the early summer of 1942 were analysed in a similar fashion in order to elucidate the development of the raids, as far as the limited photographic evidence would allow, and wherever possible to make recommendations as to how the bombing techniques might be improved. In order that the results should be of the maximum operational value, and that use could be made of them in the planning of future operations, every effort was made to publish them within a week of the operation.

At the end of April 1942, after Gee had been in operational use for nearly two months, an attempt was made to assess the overall effect which its introduction had had on the success of Bomber Command operations. Although this was by no means as great as had been hoped for or expected, an appreciable improvement in our bombing under certain conditions was noted.[2] Thus, for raids on Ruhr targets in moderate weather conditions, the percentage of successful photographs showing the target area increased from 11 per cent over the period June 1940 to February 1942 to 18 per cent during the months of March and April 1942, when Gee was used. In addition, there was a marked improvement in the percentage of sorties reporting attack on the primary target, an effect which was almostcertainly attributable to the introduction of Gee. A more extensive analysis along the same lines was carried out early in 1943, and compared the percentage of plottable photographs which were within three miles of the aiming point for a period of seven months before and six months after the introduction of Gee.[3] This confirmed the findings of the earlier analyses that the beneficial effects of Gee were confined to raids in certain weather conditions and on certain classes of target. As might have been expected in view of its limited range, the improvement was most marked against the shorter range targets, and under conditions which were unfavourable for visual identification i.e. cloudy, hazy or moonless conditions. Under optimum conditions of bright moonlight and good visibility there was no evidence that Gee had had any significant effect on the results of operations.

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(1) 'Attack on Essen, 10/11 March 1942.' Bomber Command O.R.S. Report No. B.103. (A.H.B./IIH/241/22/12)

(2) 'Appreciation of Success of Bomber Command Operations, March to April 1942, from evidence of Night Photographs (with particular reference to the introduction of T.R.1335).' Bomber Command O.R.S. Report No. S.46. (A.H.B./IIH/241/22/14).

(3) 'A Review of Night Bombing Operations.' Bomber Command O.R.S. Memo. No. M.63. (A.H.B./IIH/241/22/3).

The fact that Gee enabled successful attacks to be carried out without the assistance of moonlight was of considerable importance from the point of view of reducing casualties from enemy fighter attacks and from April 1942 onwards it became the policy to attack targets in Germany chiefly in the non-moon period.

Enemy interference with the Gee system was first suspected on the night of 6/7 August 1942, and was confirmed, beyond reasonable possibility of doubt on the raid on Osnabruck on 9/10 August ~~Bomber Command O.R.S. No.~~ ~~(Report S.60)~~.(1) The effect of this jamming was to reduce the effective range of Gee from about 400 miles to 250 - 300 miles from Daventry, with the result that all German targets were outside coverage. Consequently, Gee could no longer be used as an aid to target identification and bombing on German targets, though it was still of considerable use as a navigational aid over the greater part of the route. Although from time to time the situation was temporarily improved by the introduction of various countermeasures,(2) ~~Nos.~~ ~~(Reports S.61 and S.62)~~, it became clear that the Shaker and Samson techniques would have to be abandoned, and new methods of target marking devised.

Apart from the general research into the tactical employment of Gee, a considerable amount of research was carried out with a view to increasing its accuracy and in connection with the jamming of the device by the enemy. These aspects are discussed in detail in Chapter 11.

The Pathfinder Force and its effect on Operations

Formation of Pathfinder Force and early Pathfinding Methods

The formation of specialist squadrons to initiate raids was recommended by the O.R.S. as early as December 1941(3) and the subject of a special target finding force was much under discussion during the first half of 1942. At a meeting on 16 April, attended by representatives of the O.R.S., the Commander-in-Chief stated that he personally was 'entirely against anything that would result in the creaming off of squadrons, owing to its effect on morale'(4) and it was consequently not until July 1942, after a long and troubled period of gestation, that the Pathfinder Force was finally born, its birth precipitated by the crisis which had arisen as a result of the enemy jamming of Gee. The first operation led by the Pathfinder Force was that against Flensburg on 18/19 August.

Owing to the preoccupation of O.R.S. 1 at this time with problems connected with the jamming of Gee, no detailed accounts of the early Pathfinder raids were published, but from time to time general reviews of the situation were undertaken in order to assess what effect the Pathfinder Force was having on the general success of operations. The basis of most of the techniques used by the Pathfinders in the latter part of 1942 was visual marking of the aiming point with salvoes of 250 pound incendiaries ('blob fires') in the light of flares or as at Frankfurt on 24/25 October, in

(1) 'Gee Interference to 11/12 August 1962.' Bomber Command O.R.S. Report No. S.60. (A.H.B./II/69/210).
(2) 'Final Report on Gee Interference to 19 August 1942' and 'Gee Interference 20/21 August 1942.' Bomber Command O.R.S. Reports Nos. S.61 and S.62, (A.H.B./II/69/210).
(3) 'The Success of Night Bombing Attacks, An Appreciation.' Bomber Command O.R.S. Memo. No. M.88. (A.H.B./IIH/241/22/3).
(4) Bomber Command File B.C./S.264 19 Encl. 74A

moonlight. Occasionally coloured flares were used, either for marking the aiming point or the extremities of the target. Flares were dropped on Gee, on targets where this was available, but usually other methods, such as a timed run from a nearby landmark, had to be used by the first aircraft to reach the target. A marked advance in the technique of illumination was made on 16/17 September, when the flare force was for the first time differentiated into 'Finders', whose function was to drop long sticks of flares right across the target area, and 'Illuminators', who were detailed to illuminate the aiming point itself with much shorter sticks of flares.

Analyses of Early Pathfinder Raids

A preliminary report on the first 13 Pathfinder operations[(1)] indicated that six of these had yielded better results than would have been expected on the basis of previous experience against these targets. Of the remaining seven operations, four achieved similar results and three were less successful than past raids. On two of the latter raids failure was due to the fact that the wrong target was attacked.

A more extensive and detailed investigation into the first 21 attacks led by the Pathfinder Force, covering the period 18/19 August to 20/21 November 1942 was made at the end of 1942.[(2)] As in the previous preliminary report the effect of the Pathfinder Force on the results achieved was based on night photographic evidence, rather than on the amount of damage caused to the target, since the latter depended on many factors, such as target size, bomb-loads carried and type of buildings in the target area, on which the Pathfinder Force obviously had no influence. The criterion of success was again taken as the percentage of photographs plotted within three miles of the aiming point and this was compared with the corresponding percentage which would have been expected in the absence of the Pathfinder Force, as estimated from results of earlier raids. In addition, special attention was paid to those raids on which the Pathfinders did not carry out their planned technique with complete success, in order to ascertain the chief causes of failure.

This investigation brought to light many points of operational importance with regard to the illumination and marking of targets by the Pathfinder Force. Thus, the complete or partial failure of at least five raids was established as being mainly due to an inadequate number of finder aircraft, of which it was estimated that at least eight to 12 were required on normal targets, particularly when weather conditions were not expected to be ideal. On past raids the number of finders employed had usually been considerably less than this. In addition it was fairly clear that the present flare fuze was not functioning satisfactorily and numerous cases were reported by crews of flares opening too high, thus failing to illuminate the ground properly and

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(1) 'Assessment of the success of Operations led by the Pathfinder Force', 18/19 August to 16/17 September 1942. Bomber Command O.R.S. Internal Memo. No. M.

(2) 'The Effect of the Pathfinder Force on Night Bombing Operations, August to December 1942'. Bomber Command at O.R.S. Internal Memo. No. M. 117. (A.H.B./IIH/241/22/3).

at the same time causing considerable dazzle. It was therefore recommended that a special investigation should be made to determine whether the fuzes needed recalibrating, and that the development of the new barometric fuze should be pushed forward as quickly as possible.

The same investigation also showed that the methods of ground marking then in use were not entirely satisfactory. The salvoes of 30 pound and 250 pound incendiaries dropped by the visual markers were often difficult to see, especially while the target was illuminated by flares, and 'Pink Pansies' (4,000 pound gel ignite incendiaries) which had been used for marking on a few raids, although very distinctive whilst bursting, did not leave any permanent mark. There was clearly a great need for special coloured marker bombs. The prototypes of such bombs had already been prepared and tested by the M.A.P. and it was recommended that they should be introduced into operations with the least possible delay.

In general it was found that up to 20/21 November 1942 the Pathfinder Force had been successful in carrying out their planned target marking technique in one third of the attacks on Germany which they had led, and partially successful in almost another third. Although these results do not on the surface appear very creditable, it must be remembered that target marking methods were at this stage still in the experimental stage, and that the Pathfinder Force was not as yet composed of experts. Moreover they were not during this period provided with any special navigational or target finding or marking equipment, and on German targets enemy interference had deprived them of the use of Gee. Against Italian targets, where the weather was usually better and the defences less heavy than over Germany, results were much more satisfactory, the target marking failing on only two out of nine occasions.

New Problems introduced as result of Target-marking

During 1941 and the early part of 1942 it was the responsibility of each individual crew to identify and bomb the detailed aiming point. The errors due to misidentification and, to a lesser extent to bad bomb-aiming, were often very large, but, on the whole were distributed in a random manner about the aiming point. Special cases giving rise to a typical bomb patterns did, of course, occur from time to time, as when any considerable proportion of the force was diverted from the target by decoy activity or other causes, but in general the result of this type of bombing was a widely dispersed pattern of bombs whose ~~[illegible]~~ mean point of impact (M.P.I) was on or close to the aiming point. The chief problem which faced the Command at this time was how to reduce the random error of bombing, and the introduction of the technique of target marking by a special Pathfinder Force, was, in fact, an attempt to solve this problem. This attempt was highly successful and ~~[illegible]~~ (1). resulted in an immediate and very considerable reduction in the random error of bombing.(2) At the same time, however, another serious source of error was

~~(1) [illegible] (Bomber Cmd O.R.S. Int Mem No. [illegible])~~

/ introduced

introduced. As the Main Force were no longer detailed to aim at the aiming point itself, but at marker bombs dropped by the Pathfinder Force, the M.P.I. of the resulting bomb-pattern no longer coincided with the aiming point but was determined largely by the position of the marker bombs. Any errors in placing the markers therefore were likely to be perpetuated throughout the whole attack, causing the M.P.I. of the bombing to be displaced from the aiming point. The distance between the M.P.I. of the bombing and the aiming point was known as the overall systematic error and from the time of the introduction of the Pathfinder Force the question of how to reduce this source of error to its lowest possible limit was the chief problem confronting the A.D.C., P.F.F. and one to which O.R.S. gave particular attention. Although much was done during 1943, 1944 and 1945 to reduce the magnitude of this error by improving the accuracy of the marking methods used, the problem was one that was never completely resolved.

In the seven months prior to the introduction of the Pathfinder technique only about 14 per cent of all raids carried out showed any marked displacements of the M.P.I. of bombing from the aiming point, whereas during the following seven months something like 67 per cent of attacks showed an appreciable systematic error. The effect of this on the overall success of operations is strikingly illustrated by the following statistics:-(1)

	Period March 1942 to August 1942 (Pre-P.F.F.)	Period August 1942 to March 1943 (P.F.F.)
Overall percentage of photos plotted within three miles of centre of concentration	35%	50%
Overall percentage of photos plotted within three miles of aiming point	32%	37%

As the above figures indicate, the considerable increase in concentration achieved as a result of the introduction of the Pathfinder Force was largely offset by the introduction of systematic errors, so that the overall increase in efficiency of the Command during the first six months of the P.F.F. was comparatively small. As in the case of Gee the advantages conferred by the Pathfinder Force were found to be greatest for raids in moderate weather conditions.

Further Development of Pathfinding Methods

Up to the end of 1942 the Pathfinder Force had no radar aids to assist them in their task of target finding and no special markers to enable them to mark the target satisfactorily. Early in 1943 both these handicaps were removed and a new era in the technique of target marking was initiated. Oboe Mark 1 was first brought into use for the raid on Dusseldorf on 31 December 1942/1 January 1943., target indicator groundmarkers on Berlin on 16/17 January, and H2S on Hamburg on 30/31 January. The introduction of all these devices presented a new series of tactical problems which engaged the

(1) 'A Review of Night Bombing Operations over a Period of 19 months, August 1942 to February 1943.' Bomber Command Internal Memo. No. M.63. (A.H.B./IIH/241/22/3).

attention of O.R.S., throughout 1943 and the early months of 1944 and which are described more fully in the chapters on the operational use of H2S and the operational use of Oboe.(1)

Organisation and Efficiency of the Pathfinder Force

In addition to these detailed researches into the marking techniques used, the O.R.S. also carried out investigations of wider scope into the general organisation of the Pathfinder Force, and from time to time made recommendations as to how the efficiency of the force might be increased. An example of such recommendations was contained in an internal memorandum(2) which was prepared by the O.R.S. at the request of the Commander-in-Chief after consultation with the Air Officer Commanding Pathfinder Force. In this report the method of selecting crews for the Pathfinder Force was investigated and two alternative methods of selection were suggested. It was also suggested that the training of potential marker crews, which consisted of a five-day course at the Navigation Training Unit, was inadequate to fit them for the difficult and important duties which they had to carry out. The bulk of the specialist training of Pathfinder crews was in fact done on operations and was consequently spread over a considerable period. This system had proved both wasteful and inefficient since not only were a considerable number of the potential marker crews missing before they were fully trained, but the success of operations was constantly jeopardised by the presence of partially trained markers. Recommendations were therefore made that the Navigation Training Unit course be lengthened to a minimum of two weeks, which would give sufficient time for a thorough grounding in the use of special apparatus, particularly H2S, and would enable a preliminary assessment of the capabilities of each crew to be made. At the same time a readjustment of the establishment of the Pathfinder squadrons was suggested, so that each potential marker crew, after completing five operations as supporter could be stood down for one week of intensive specialist training, either as a blind marker, a visual marker or a backer-up.

Consideration was also given to the number of Pathfinder crews necessary to carry out a satisfactory H2S attack and the conclusion was reached that the strength of the Pathfinder Force at that time (August 1944) was not really adequate for marking more than one target outside Oboe range per night, when conditions were such that provision for a skymarking attack would have to be made.

Reports describing Pathfinder Methods

Study of the sortie raid reports returned by Main Force crews in 1943 had revealed a state of ignorance on the part of many crews, concerning Pathfinder methods and it was obvious that many did not understand even the

(1) See Chapters 12 and 14.

(2) 'Recommendations for increasing the efficiency of the Pathfinder Force, 1 September 1944.' Bomber Command O.R.S. Internal Memo. No. M-64.

basic principles of the marking methods employed, or the difficulties with which the Pathfinder crews had to contend. It was in an attempt to improve this state of affairs and to bring about a better understanding between Main Force and Pathfinder crews that the O.R.S. prepared at the end of 1943, a somewhat popularised account of 'Methods of Target Marking'.(1) This paper was printed and was issued by Headquarters Bomber Command for distribution to all Bomber Command stations. A second, revised edition was published in March 1945.

At about the same time a more detailed account of the use of H2S for target marking at night was prepared for the guidance of the Northwest African Air Forces who at that time were being equipped with H2S and were forming a Pathfinder Force of their own.(2)

The O.R.S. was also responsible, in conjunction with the Directorate of Camouflage, Ministry of Home Security, for the production of a series of lantern slides illustrating the development of various types of attack. These slides were intended to be used to illustrate lectures to advanced pupil-crews on methods of target marking, assessing of aiming points, dangers of under-shooting and the like. Full details of this work will be found in Chapter 9.

The Operational Use of H2S

Use of H2S in Bomber Command

H2S was essentially different from its predecessors, Gee and Oboe, in that the whole of the equipment was airborne so that there were no limitations imposed by range from ground stations as in the case of previous radar devices. Preoperational trials carried out by the Telecommunications Flying Unit (T.F.U.) in June-July 1942 had indicated that towns and similar constructions of appreciable size could be picked out from other ground features, and that land could be clearly distinguished from water. Although the shape was somewhat distorted and the definition poor, some degree of identification was possible. It was clear that in spite of its shortcomings, the potential value of the equipment to Bomber Command was very great, and it was consequently decided to go ahead with the production of Mark 1 equipment.

H2S was originally designed to enable an aircraft to drop its bombs on a built-up area, but as it would obviously be some considerable time before any appreciable proportion of the bomber force could be equipped and trained, it was decided, as an interim measure, to employ it as a Pathfinding device. The first production sets were consequently made available in November 1942, to the Pathfinder Force and by January 1943 two flights of aircraft had been equipped. At the end of September 1943 all the heavy aircraft of the Pathfinder Force had been equipped and by February 1944 23 squadrons of the main force also had H2S.

(1) A.H.B. Narrative, 'The R.A.F. in the Bombing Offensive against Germany, Volume VI, Annex B.'

(2) 'The Use of H.2.S. for Target Marking at Night, 21 December 1943.' Bomber Command O.R.S. Internal Memo. No. M.100. (A.H.B./IIH/241/22/3).

At this time there was much discussion as to whether H2S should continue to be used as a Pathfinder device, or should be employed for blind bombing by the main force, the purpose for which it was originally designed. The most powerful opinion favoured the view that its primary use should continue to be for target marking, and that the main force should use H2S for navigational purposes only, and this was the policy which was followed by the Command.(1)

O.R.S. contribution to development of H2S target-marking Techniques

As in the case of Gee and, to a lesser extent, Oboe, the use of H2S for target marking brought with it a new series of tactical problems which engaged the attention of O.R.S. throughout 1943 and the early part of 1944. In general the method used in solving these problems was one of trial and error, and the part played by the O.R.S. consisted largely of pointing out to the Air Staff of Bomber Command and to the Air Officer Commanding Pathfinder Force where they considered errors had been made, and in suggesting improved methods which might be tried on subsequent operations. Sometimes the reasons for the failure or the partial failure of an operation were fairly obvious, but usually this was not the case and a very detailed intensive study of the development of the raid was often necessary before any definite conclusions could be reached as to the primary cause of failure, or suggestions made as to how the same mistake could be avoided in future operations. Detailed studies of this type were carried out for nearly all the major raids in 1943 and the early part of 1944 for which night photographic evidence was available. A full account of the methods of analysis used will be found in Chapter 12, and will not be referred to in detail in the following paragraphs, the purpose of which is to describe the results achieved, and to show how, and to what extent, this work by the O.R.S. contributed to the development of successful H2S marking techniques. The marking techniques used were at first fluid, often varying widely from night to night, but gradually, as experience was gained, undesirable features were eliminated, improvements were introduced, and the techniques became more and more established. In order to appreciate fully the problems involved and the advances made it is necessary first of all to describe the marking techniques used on the early H2S raids.

Techniques used on early H2S Attacks

The average number of H2S equipped aircraft dispatched per raid during the first two or three months of 1943 was about 14, of which four were usually detailed to attack at zero hour and the remainder were spread throughout the attack at intervals of one, two or three minutes depending on the length of the raid. In view of the uncertainty of weather conditions over the target, particularly in the amount of haze which would be encountered, each H2S aircraft normally carried reconnaissance flares, target indicators plus markers and two-coloured skymarking flares, and it was left to the discretion of the Captain

(1) Mins. of Mtg., 22 Apr. 1944 (B.C./S.28808/2, Vol. III, Encl. 10B.

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whether he should illuminate, groundmark or skymark the target. When the weather was obviously not going to be good enough for visual identification of the target, as on the first two H2S operations, illuminating flares were not carried, and the target was groundmarked with target indicators or skymarked with coloured flares depending on the amount of cloud encountered. It was realised that H2S was not as precise a marking device as Oboe, and that a certain scatter of markers was to be expected, though there was at this time little information on how great this scatter was likely to be. In order to overcome this difficulty an averaging technique was used, the main force being instructed to aim their bombs, not at a particular target indicator marker, but at the M.P.I. of all the markers seen. In order to assist them to identify the M.P.I. and to ensure continuity of marking throughout the raid a new type of marker aircraft was introduced, the backer-up (later known as a Visual Centrer), whose function was to estimate the M.P.I. of the target indicators dropped by the blind markers and to mark this point with target indicators of a second colour. Five backers-up were used on the first H2S operation but on subsequent raids this number was increased to about 20, as five were found to be quite inadequate to maintain the necessary concentration of markers. When conditions were good enough for illumination of the target, the backers-up were detailed to aim their salvoes of target indicator markers visually at the aiming point in the light of the flares.

The above plan of attack which appeared theoretically sound and which seemed, on paper, to be practically foolproof, in practice proved unsatisfactory in many respects. During the first two months after its introduction 15 major operations using H2S were carried out, but of these only three caused any appreciable damage to the target. Nevertheless, in spite of these somewhat disappointing results, valuable experience was gained and many tactical lessons were learnt which enabled further and more successful techniques to be devised.

<u>Tactical Lessons learnt from Analyses of early H2S Operations</u>

During February and March 1943 O.R.S. carried out detailed investigations into ten raids on which H2S was used for target marking, the results of which were published in reports of the 'B' Series for distribution within the Command. A summary was made of the difficulties encountered on these early H2S operations and of the tactical lessons learnt.(1) ~~will be found in Bomber Command O.R.S. (B.C.) Report No. B.151.~~

One of the chief reasons for the lack of success of these early H2S operations was found to be the very small number of primary target indicators (i.e. those dropped blindly on H2S) which were burning at any one time during a raid. Detailed time analyses of the raids showed that it was unusual for the

(1) 'Review of H.2.S. Groundmarking Raids on Germany, February to April 1943.' Bomber Command O.R.S. Report No. B.151. (A.H.B./IIH/241/22/12).

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early backers-up when they arrived at the target, to find more than one or two primary target indicators burning on the ground, instead of the five or six expected. It was consequently very difficult for them to centre the raid accurately and it was often possible for any single primary target indicator, irrespective of its accuracy, to attract the backers-up: many raids were for this reason a long way off-centre. Apart from the comparatively few H2S-aircraft available at this time and the low serviceability of the equipment during the first few months (only 55 per cent of sorties arrived in the target area with serviceable sets) several other factors contributed to this sparseness of primary marking. It was found, for example, that of the crews who arrived in the target area with serviceable equipment rather less than half actually used it for blind marking, the remainder releasing their target indicators visually, often simply backing-up markers already down and thus defeating the averaging technique. The few aircraft which did use their H2S for blind marking often made large errors and the situation was further aggravated, especially on the longer range targets by poor timing of the marker aircraft. The latter was partly due to the fact that the Stirlings, which at this time comprised about half the marker force, had a very small tolerance in speed.

In order to overcome these difficulties the O.R.S. made a number of recommendations, most of which were subsequently adopted by the Pathfinder Force. Amongst the most important of these were:-

(a) That Pathfinder crews whose H2S was working satisfactorily must use it for marking, and must not be tempted to release on visual identification. The dangers of relying on visual identification were well illustrated by the raid on Wilhelmshaven on 18/19 February 1943 when several of the blind markers, attempting to release visually, mistook a line of smoke generators for the coastline and, as a result, centred the attack some five miles from the aiming point.(1)

(b) That the blind markers, instead of being spread throughout the attack, should all be detailed to attack at the beginning of the raid (at zero minus one), or if considered necessary, in two waves, one at the beginning and one in the middle of the raid. This plan was adopted at Wilhelmshaven on 19/20 February 1943 and on all subsequent H2S raids.(2)

(c) In view of the fact that raids on which visual marking in the light of flares laid by H2S aircraft had been used as the primary marking method had proved much more successful than those on which purely blind marking was employed, it was recommended that this technique be used whenever weather conditions

(1) 'Interim Report on the Attack on Wilhelmshafen, 18/19 February 1943.' ~~Bomber Command O.R.S. Report No. B. 123. (A.H.B./IIH/241/22/12).~~

(2) 'Interim Report on the Attack on Wilhelmshafen, 19/20 February 1943.' Bomber Command O.R.S. Report No. B. 124. (A.H.B/IIH/241/22/12).

conditions would permit.(1) This recommendation was also adopted by the Pathfinder Force and formed the basis of the 'Newhaven' method (see below).

(d) The raid on Wilhelmshaven on 19/20 February was shown to have gone astray owing to the fact that H2S operators mistook a new suburban area to the north for the town iself.(2) This suburban area was not shown on the H2S target maps used. Since it was probable that many other of the H2S target maps then in use were similarly out of date it was recommended that the maps of possible H2S targets be revised from the latest air cover, and instructions that this be done were issued by the Deputy Commander-in-Chief.

These difficulties of achieving satisfactory primary marking of the target using H2S were by no means the only ones encountered. It was found, for example that even on raids where the primary marking was satisfactorily accomplished that the attack as a whole was very rarely centred on the primary marker and time analyses revealed that there was a marked tendency for the raid to 'creep' backwards along the line of approach. The analyses also revealed that this shift in the centre of the attack was largely attributable to the backers-up who showed a strong tendency to undershoot the main concentration. Since these aircraft dropped their target indicators at intervals throughout the raid, each aiming at the centre of the target indicators already dropped, this undershooting was cumulative, and as a result it was possible, in an attack of 25 minutes duration, for the M.P.I. to shift by as much as several miles. One of the factors contributing to this undershooting was the fact that, at this time, no allowance was made for the fact that the target indicator markers burst in the air and that their forward travel was thus arrested. A suggestion was made(3) that this factor should be allowed for by introducing a carry time of approximately three seconds for all aircraft dropping target indicators and this was subsequently accomplished by appropriate modification of the distributor. This action, although a step in the right direction, by no means eliminated undershooting and consequent shift in the centre of the attack, which remained throughout 1943 one of the most serious problems of target marking. Various theories were put forward to account for this effect and a number of suggestions were made by the O.R.S. and others as to how this drift of the attack might be arrested. It was clear, for example, from some of the analyses of early H2S attacks, that many backers-up and main force aircraft were not in fact aiming at the M.P.I. of the marker pattern, but were taking aim at the first target indicators encountered. This might well have been due in some cases to a not unnatural desire to get rid

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(1) 'Review of H2S Groundmarking Raids on Germany, February to April 1943'. Bomber Command O.R.S. Report No. B.151. (A.H.B./IIH/241/22/12).

(2) 'Interim Report on the Attack on Wilhelmshafen, 19/20 February 1943'. Bomber Command O.R.S. Report No. B.124. (A.H.B./IIH/241/22/12).

(3) 'H2S – Groundmarking Attack on Turin, 4/5 February 1943'. Bomber Command O.R.S. Report No. B.122.

of the bombs as soon as possible; but another important factor was the relative visibility of different target indicators from the air, those that were lying short of the target in open country being much more easily seen than the more distant ones on the target itself which were often partially hidden by buildings or obscured by smoke. Attempts to eliminate undershooting proving unsuccessful, suggestions were put forward for counteracting its effects, either by detailing the Backers-up to aim at the far side of the concentration of markers,[1] or by choosing an aiming point well toward the far side of the vulnerable area of the target.[2] The technique of 'recentring' with H2S at intervals throughout the raid was also tried. All of these procedures had a certain amount of success and led to some improvement in the situation, but the real solution of the problem did not come until 1944 when, by employing smaller forces and by further concentrating the aircraft in time, it became possible to limit the attack to the duration of the primary marking, thus to a large extent eliminating the necessity for Backers-up.

The Newhaven Technique

As a result of the experience gained during February and March and of the lessons learnt from the analyses of the early H2S raids, the Newhaven technique was developed by the P.F.F. in April 1943, and proved so successful that, with various minor modifications, it remained the standard H2S marking technique until the end of the war.

In the original form of the Newhaven method the attack was opened by a wave of H2S aircraft, all detailed to attack at the same time, who would blind-mark the target with target indicators and at the same time illuminate it with sticks of flares. These Blind Marker Illuminators, as they were called, were followed after an interval of about two minutes by a smaller number of Visual Markers, whose function was to identify aiming point visually in the light of the flares and to mark it accurately with target indicators of a distinctive colour. If they were unable to do this, on account of weather or any other reason, they would refrain from dropping their markers. Finally came the Backers-up, attacking at the rate of one or two per minute throughout the duration of the attack, who would either back-up the Visual Marker's target indicators or, if these had not been dropped, would centre the attack on the M.P.I. of the Blind Marker's target indicators. The later Backers-up, arriving after the primary markers had died out, would continue to back-up the target indicators of previous Backers-up.

On the early Newhaven attacks both the Visual Markers and the Backers-up both used the same colour target indicators. This was a highly dangerous procedure since the Backers-up had no means of telling whether they were in fact backing up the primary marking, or were simply aiming at target indicators

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(1) 'The Operational Use of H2S, January to May 1943'. Bomber Command O.R.S. Report No. S.99. (A.H.B./II H/241/22/14).
'Review of H2S Groundmarking Raids on Germany, February to April 1943'. Bomber Command O.R.S. Report No. B.151. (A.H.B./II H/241/22/12)
(2) 'Attack on Le Creusot and Montchanin, 19/20 June 1943'. Bomber Command O.R.S. Report No. B.144. (A.H.B./II H/241/23/12).

dropped by previous backers-up which might or might not be accurate. It was also unsatisfactory from the point of view of the main force who had no method of distinguishing the more accurate visual target indicators from the less accurate secondary target indicators. This plan of attack was partly responsible for the poor results of the attack on the Skoda Works at Pilsen on 13/14 May 1943(1) which led the O.R.S. to put forward a suggestion for a modified form of Newhaven attack employing target indicators of three different colours. It was suggested that the blind markers should use yellow target indicators, the visual markers red, and the backers-up green. The three colour Newhaven was first tried out on the Pathfinder Force experimental raid on Munster on 11/12 June 1943, and remained in general use throughout 1943. The use of yellow target indicators by the blind markers was eventually abandoned when, early in 1944, the hooded flare came into general use, since it was found that these flares when viewed through haze were liable to be mistaken for yellow target indicators. This was thought to have led to some confusion on the raid on Frankfurt on 20/21 December 1943(2) and on subsequent attacks the colour scheme was changed to green for blind marking, red or large salvoes of mixed red and green for visual marking, and green for backing-up. The first raid on which this modified colour scheme was tried (Stettin 5/6 January 1944) was not an outstanding success(3) but on subsequent operations the scheme proved reasonably satisfactory.

The great virtue of the Newhaven method was that, should the weather prove unsuitable for visual marking of the aiming point, the attack would automatically develop as a Blind H2S Groundmarking raid. In 1943 over half our Newhaven attacks did, in fact, develop in this manner, but during 1944 and 1945, as the efficiency of the illumination and the skill of the visual markers increased, an ever increasing proportion of H2S attacks developed as Visual Newhavens. This was one of the many factors contributing to the steady improvement in the efficiency of the P.F.F. and consequently the Command as the war progressed.

H2S Skymarking Attacks

When the weather forecast showed a chance of considerable cloud over the target provision was usually made for a skymarking attack as an alternative to Newhaven or Blind H2S Groundmarking. In attacks of this type the H2S aircraft released skymarking flares of a characteristic colour, and the main force were instructed to aim at the M.P.I. of these flares. Owing to the drift of the flares the usual backing-up techniques could not be employed on skymarking attacks, and in order to maintain an adequate concentration of flares it was necessary to plan for H2S aircraft to attack at intervals throughout the duration of the raid. The timing requirements for an H2S skymarking attack were therefore incompatible with those for an H2S groundmarking attack, where it was necessary to plan for a maximum concentration of blind markers at the beginning of the raid.

(1) 'Attack on Pilsen, 13/14 May 1943.' Bomber Command O.R.S. Report No. B.139. (A.H.B./IIH/241/22/12).

(2) 'Attack on Frankfurt, 20/21 December 1943.' Bomber Command O.R.S. Report No. B.189 (A.H.B./IIH/241/22/12).

(3) 'Attack on Stettin, 5/6 January 1944.' Bomber Command O.R.S. Report No. B.192 (A.H.B./IIH/241/22/12).

The P.F.F. attempted to solve this problem by dividing the blind marking force into two sections, known respectively as primary and secondary blind markers. The primary blind markers would attack at the beginning of the raid, dropping either target indicator markers or skymarking flares, according to cloud conditions, while the secondary blind markers would attack at intervals throughout the raid dropping skymarking flares only if cloud conditions were such that target indicator markers could not be seen. The minimum rate of attack for the secondary blind markers, if an adequate concentration of flares was to be maintained, was estimated by the O.R.S. to be three per minute but the available number of blind marker crews rarely enabled this concentration to be achieved. As a result the average number of skymarking flares burning over the target at any one time during the raid averaged only three or four and, in the case of some of the skymarking attacks on Berlin was as low as one or two. Such small numbers of flares were inadequate to provide a reasonable 'centre' and, in the opinion of the O.R.S. this was one of the chief causes for the disappointing results of our H2S skymarking attacks in 1943.(1) It is interesting to note that on the one occasion when a good concentration of flares was achieved, viz. Leipzig 3/4 December 1943, where the average number of flares alight at once was 6·3, a highly successful attack was carried out.

Attacks on Berlin

Berlin, one of Bomber Command's most important targets, proved itself also one of the most difficult to attack successfully. The chief sources of difficulty were the very large size of the built-up-area, which meant that it was not possible for H2S aircraft to home directly on to a precise aiming point within the limits of the city, and the absence of sufficiently distinctive landmarks in the near vicinity of the target from which dead reckoning runs could be made. In addition the long range of the target made accurate timing of the raid extremely difficult. All the H2S attacks on this target were blind ground- or sky-marking attacks, and although the possibility of using the Newhaven technique was discussed on several occasions, this method was never used against Berlin as it was considered very doubtful if it would be possible to achieve a sufficient concentration of flares before illumination was achieved and whether the visual markers would be able to identify their aiming point in such a large built-up-area.

The first raid on Berlin using H2S was on 1/2 March 1943, when the direct homing technique was used. Owing to the difficulty referred to above the H2S aircraft dropped their markers on the south-west suburbs of the city, and although extensive damage was caused in this area, the whole raid was about six miles off centre. In their interim report on this attack(2) the O.R.S. drew

(1) 'Stabilisation of Sky Marker Technique and an Estimate of the Bomb Scatter to be expected,' 2 March 1943. Bomber Command O.R.S. Memo. No. M.95. (A.H.B./IIH/241/22/3).

(2) 'Interim Report on the Attack on Berlin, 1/2 March 1943.' Bomber Command O.R.S. Report No. B.128. (A.H.B./IIH/241/22/12).

attention to the difficulties of homing on to such a large built-up-area and suggested as an alternative technique the use of a timed run from some easily identifiable point outside the target area. This method was adopted on the next attack on 29/30 March, the timed run being made from the Muggel See, which was to be illuminated with flares and identified visually. This technique proved much more satisfactory and most of the early blind markers dropped their target indicators within three miles of the aiming point.(1) Unfortunately, owing to bad weather on route, the main force failed to arrive at the target in time to take advantage of this marking, and by the time they did arrive markers had also been dropped to the south-east of the city, and it was around these that the attack eventually developed. The lessons learnt as the result of the O.R.S. analysis of this attack were summarised in a letter from Headquarters which was sent to all groups of the Command.

The relative lack of success of these early H2S attacks on Berlin had emphasised our lack of knowledge concerning the H2S responses of large built-up areas and as a result of a recommendation made by O.R.S.(2) the Command Radar Section, in cooperation with the Bombing Development Unit carried out an intensive investigation of the H2S responses of the London area. It was shown that H2S Mark II was incapable of bombing accurately an aiming point within a large city, except by reference to easily distinguishable landmarks, due to the confused nature of the response pattern, and it was further recommended that similar trials be carried out with Mark IIc and Mark III H2S before they were put into operation.(3)

On the next two large scale attacks on Berlin (23/24 August and 31 August/1 September 1943), the blind markers were detailed to release their target indicators on a range and bearing fix on a hooked projection on the northern edge of the built-up area, but serious difficulty was encountered in recognising this on the Plan Position Indicator and the target indicators again fell well to the south-west of the city. A subsidiary cause of failure on the second of these attacks was the incorrect wind forecast, which again upset the timing of the attack and brought the main force in on the wrong track.(4) On 3/4 September the Muggel See was again used as a starting point for a timed run, whilst other blind marker squadrons attempted to get an H2S fix on Brandenburg. The O.R.S. analysis of this raid,(5) showed that although it was considerably more successful than the previous two, the main concentration of bombing was again on the edge instead of in the centre of the target, and that only about one third of the bombs dropped fell on the built-up-area.

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(1) 'Interim Report on the Attack on Berlin, 29/30 March 1943.' Bomber Command O.R.S. Report No. B.132.

(2) 'Interim Report on the Attack on Berlin, 1/2 March 1943.' Bomber Command O.R.S. Report No. B.128. (A.H.B./IIH/241/22/12).

(3) 'The Nature of H2S Responses.' Bomber Command O.R.S. Report No. S.106. (A.H.B./IIH/258/3/36).

(4) 'Attacks on Berlin, 31 August/1 September 1943.' Bomber Command O.R.S. Report No. B.168. (A.H.B./IIH/241/22/12).

(5) 'Attacks on Berlin, 3/4 September 1943.' Bomber Command O.R.S. Report No. B.169. (A.H.B./IIH/241/22/12).

In September 1943, at the request of the Commander-in-Chief, a short note was produced by the O.R.S. on the possible methods of attacking Berlin with H2S.(1) The basis of the method suggested was a dead reckoning run from an H2S fix outside the target area, but since there were no reliable H2S fixes within ten miles of the centre of Berlin, it was suggested that the run be carried out in two stages. The starting point for the first stage would be an H2S fix on one of three towns within 30 or 40 miles of the target (New Ruppin, Furstenwalde or Brandenburg were suggested as suitable), whilst the second stage of the run would be started from a visual fix on a landmark within ten miles of the aiming point. The latter would be illuminated with flares and groundmarked using the Newhaven technique.

The chief objection to the use of a timed run method on a heavily defended target such as Berlin was that the evasive action normally practised was liable to make such runs very inaccurate. In order to overcome this difficulty a modification of the above scheme was put forward(2) whereby the runs would be carried out with the assistance of the Ground Position Indicator. As soon as the G.P.I. became available in the Pathfinder Force it was in fact used for this purpose, though the two stage dead reckoning run method suggested by the O.R.S. was never tried out in practice.

The main 'Battle of Berlin' started in November 1943 and continued until February 1944. During this time 15 major attacks were delivered and although the results achieved were perhaps not as great as they might have been, enormous damage was caused to the German capital. Most of these attacks were skymarking raids carried out over 10/10ths cloud and owing to the absence of photographic evidence the O.R.S. was not able to carry out its usual analyses, except in one or two instances.(3)

Mark III (three centimetre) H2S was first used by the Pathfinder Force in the Battle of Berlin, and such evidence as there is suggests that the results achieved by the Mark III equipment were somewhat better than those of Mark II.(4) There is no doubt, however, that, owing to the speed with which Mark III was brought into operation which necessitated the omission of the usual Bombing Development Unit service trials, that the best use was not immediately made of the equipment, and that it was not until later that its potentialities were fully realised.(5)

Accuracy of H2S Marking

In addition to their detailed investigations into marking techniques, O.R.S. also kept a continuous check throughout 1943 and 1944 on the accurary of blind marking with H2S. Use was made of these records in the preparation of Bomber Command O.R.S. Report Nos. S.99,(6) S.189,(7) and S.200,(8) but much of the

(1) 'Notes on Possible Methods of attacking Berlin with H2S.' Bomber Command O.R.S. Memo. No. M.

(2) 'Suggested Use of the G.P.I. for Bombing Berlin.' Bomber Command O.R.S. Report No. B.170.

(3) 'Attacks on Berlin, 26/27 November 1943 and 2/3 December 1943.' Bomber Command O.R.S. Reports B.186 and B.188. (A.H.B./IIH/241/22/12).

(4) 'An Analysis of Marking and Bombing Accuracy on H2S Groundmarking Attacks by Mosquitos, June to November 1944.' Bomber Command O.R.S. Report No. S.212. (A.H.B./IIH/241/22/14).

(5) 'The Use of H2S for Target Marking at Night,' 21 December 1943. Bomber Command O.R.S. Memo. No. M.100.

(6) 'The Operational Use of H2S, January to May 1943.' (A.H.B./IIH/241/22/14).

(7) 'H2S Blind Bombing Accuracy, 1 October 1943 to 30 April 1944.' (A.H.B./IIH/241/22/14)

(8) 'Accuracy of Blind Ground Marking by P.F.F., H2S, May to September 1944.' (A.H.B./IIH/241/22/14).

data collected, showing no essentially new features, was never published. The earlier estimates of the accuracy of H2S marking were based on the plotted positions of the photographs with bombing taken by those aircraft, who, from their raid reports were known to have bombed blindly. Later however, the increasing use of colour film at night, made it possible to associate the target indicators seen on night photographs with the aircraft which dropped them as a result of which, more reliable estimates of marking accuracy, based on the plotted positions of the target indicators dropped, could be made. The main results of these investigations into the accuracy of H2S marking are discussed in Chapter 12.

H2S Mosquito Raids

In addition to its use in heavy aircraft H2S Mark II, and later Mark III, was also fitted into Mosquito aircraft of No. 139 Squadron and, throughout 1944 and the early months of 1945, these aircraft were used to lead Bomber Command's light striking force of Mosquitos. The tactics used on these operations were very simple, the most usual being blind groundmarking by four to seven H2S-equipped Mosquitos, dropping either red or green target indicators. Backers-up were not usually employed, and the main force was detailed to bomb the M.P.I. of all markers seen. When conditions were cloudy target indicator 'floater' or skymarking flares would be used in place of the usual groundmarkers.

These raids were at first planned primarily as nuisance raids or as feint attacks to divert enemy fighters from the main target for the night, but during 1944 the light striking force increased rapidly in size and by 1945 raids of more than 100 aircraft were frequently dispatched, which played a not insignificant part in the bombing offensive. Owing to the fact that on these raids very few of the aircraft carried photo-flashes, the usual type of night photographic plot could not be prepared, and consequently practically nothing was known concerning either the marking or the bombing accuracy achieved until early in 1945 when the O.R.S. published a report on this subject.(1) The basic work for this investigation was carried out by the Allied Central Interpretation Unit ('N' Section) and was published in a series of 'N.B' Reports. These consisted mostly of plots of target indicator markers, and plots of 4,000 pound bomb flames, which however, could usually not be plotted in relation to ground detail. The O.R.S. analysis, based on this data, showed that the accuracy of H2S marking from Mosquito aircraft was the same order as from heavy aircraft viz. an average radial error of about two miles. The accuracy of the main force bombing on the markers corresponded to an average radial error of about 1·2 miles, from which it was estimated that for targets other than Berlin about 35 per cent of the bombs dropped in clear weather raids would fall on the built-up-area of the target. The corresponding figure for Berlin was estimated to be as high as 70 per cent, though this was based on a very small sample of raids.

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(1) An Analysis of Marking and Bombing Accuracy on H2S Groundmarking Attacks by Mosquitos June to November 1944. Bomber Command O.R.S. Report No. S.212. (A.H.B./IIH/241/22/14).

The Operational Use of Oboe

Methods of Using Oboe : early Proposals

Oboe was designed as a blind-bombing device, and trials during 1941 and in the early months of 1942 had indicated that the system had very great possibilities, for, although the range was at this time somewhat limited the accuracy achieved was very great. Its chief limitation as a blind bombing instrument was the fact that a pair of ground stations could only control one aircraft at a time, and that aircraft could only be brought on at the rate of one every ten minutes, which meant that only very small scale attacks could be carried out. In order to overcome this disadvantage the Air Warfare Analysis Section in May 1942 put forward a proposal for using Oboe-equipped Lancasters to lead formations of bombers on to the target at night. The problem of formation keeping at night was to be solved by an infra-red-cum-A.I. device.(1) Using such a technique they estimated that a force of 24 Lancasters could damage a synthetic oil plant, such as Gelsenkirchen/Nordstern, sufficiently to reduce its output by 89 per cent.

The O.R.S., although agreeing in principle with these proposals, did not consider them very practicable owing to the considerable time which would be required to develop the necessary instruments for night formation flying, and in June 1942 proposed an alternative scheme for using Oboe.(2) It was suggested that two Oboe aircraft, controlled by a single pair of ground stations could be employed to drop coloured marker bombs at intervals of 10 minutes throughout the raid, to act as a guide to the target marking force. It was envisaged that later, when further channels became available, the Oboe aircraft could attack at more frequent intervals, thus achieving continuous marking of the aiming point, but as an immediate measure it was recommended that two ground stations should be set up and six aircraft equipped. It was also recommended that the necessary training of crews should be started immediately. These proposals were submitted through the Deputy Commander-in-Chief to the Air Ministry, who promised that the necessary equipment would be provided on the highest priority. It was at first intended to equip Wellington IV's, but it was afterwards decided that Mosquitos owing to their higher operational ceiling would be more suitable.

The proposal by O.R.S. to use Oboe for marking proved to be one of the greatest importance. Not only was the effectiveness of attacks on area targets greatly increased but its use enabled the attack of a wide variety of targets in support of the invasion and subsequent land battle to be planned with confidence and executed with great precision.

First Oboe operations

By December 1942 the ground stations were ready and six Mosquitos of No. 109 Squadron had been equipped, and on the night 20/21 December, the first Oboe operation was carried out. This was a calibration raid on Lutterade in which only Oboe aircraft took part, each dropping three 500 pound bombs. Similar attacks by small numbers of Oboe aircraft were made at intervals during December and January, mostly on steel works in the Ruhr,

/mainly

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(1) 'On the operational use of Oboe, with a plan for destroying Gelsenkirchen in one attack.' A.W.A.S. Paper No. B.R.A.7 dated May 1942. (A.H.B./II/69/231(A)).

(2) 'The use of Oboe Mark I for target location.' Bomber Command O.R.S. Report No. S.53. (A.H.B./II/69/231(A)).

mainly with the object of completing the training of the aircrews. As a result of a detailed investigation of Photographic Reconnaissance Unit cover and information from Intelligence sources the O.R.S. estimated that the accuracy achieved on these training and calibration raids was of the order of 650 yards, though on some occasions errors of up to one and a half miles were noted.[1]

Oboe Skymarking attacks on Essen

Owing to the bad weather prevailing in January 1943 it was not possible to employ Oboe for groundmarking as had been suggested by the O.R.S. and an alternative skymarking technique was devised. Each Oboe aircraft was to mark the release point with four bundles of three flares, red with green stars, and the main force were detailed to aim their bombs at the flares whilst flying at a definite predetermined height and heading. Prior to 17 January 1943 there were seven Skymarking attacks against Essen but only on one of these raids was there sufficient night photographic evidence for a detailed analysis to be carried out.[1] This was the raid on 9/10 January 1943, an account of which will be found in the appendix to the above report. The main weight of the bombing was shown to have fallen about two miles south-west of the aiming point and the reasons for this systematic error are discussed in the report. Nevertheless this raid achieved considerably greater success than previous attacks on Essen, about 60 per cent of the aircraft bombing within three miles of the aiming point; the highest percentage previously achieved on this target being 20 per cent. Moreover, the O.R.S. analysis showed that part of the spread of the attack was attributable to the inexperience of the main force in bombing skymarkers, and it was anticipated that even better results might be achieved on future Oboe skymarking attacks. As such attacks were invariably carried out over 10/10ths cloud, however, there was rarely any night photographic evidence on which to base any estimates of success; neither was it possible in most cases to obtain reliable crater plots. Consequently little further work on this type of attack was done by the O.R.S., though a short report was published on the outstandingly successful Oboe skymarking attack on Cologne on 28/29 June 1943, by a force of 608 aircraft, which devastated nearly 1000 acres of the city on the western side of the Rhine.[2]

Oboe Groundmarking attacks

On these operations the Oboe aircraft dropped 'primary' target indicator markers, usually red in colour, on the aiming point at the shortest possible intervals throughout the raid. In order to ensure continuity of marking other aircraft dropped secondary markers, usually green in colour, aiming them visually at the target indicator markers dropped by the Oboe aircraft. The main force were instructed to aim their bombs at the primary target indicator

/markers

(1) 'Report on Oboe Operations to 16/17 January 1943.' Bomber Command O.R.S. Report No. S.78. (A.H.B./IIH/241/22/14).

(2) 'Attack on Cologne, 28/29 June and 3/4 July 1943. Bomber Command O.R.S. Report No. B.149. (A.H.B./IIH/241/22/12).

markers, if any were visible, otherwise, they were to aim at the centre of the concentration of the secondary target indicators.

The first Oboe groundmarking raid was carried out against Dusseldorf on 27/28 January 1943. This raid, however, was only on a small scale and was marred by bad weather. The first large scale Oboe ground-marking attack was against Essen on 5/6 March 1943 and was outstandingly successful. Although the weather was only moderate it is estimated that 78 per cent of the force of 442 aircraft bombed within three miles of the aiming point, and study of post-raid cover revealed more than 680 acres of devastation. It appeared that the key to successful night raiding in the Ruhr had at last been found, and this hope was fully confirmed by subsequent groundmarking raids.

In view of the consistently good results achieved with Oboe from the date of its introduction, less attention was devoted by O.R.S.1 to these raids than in the case of H2S attacks, where, as already explained (page 71) great difficulty was experienced in developing a reliable marking technique. Nevertheless during the course of 1943 interim analyses of 13 Oboe groundmarking raids were carried out and published, particular attention being paid to the less successful raids, since it was from these that the most valuable lessons were likely to be learnt.

The first such attack to be analysed was that on Cologne on 26/27 February 1943.(1) This attack started well but later deteriorated. The primary cause of the deterioration was low serviceability of Oboe, only one of the four aircraft detailed dropping its markers, but the situation was aggravated by a red target indicator dropped two and a half miles to the south-west of the aiming point, apparently by a backer-up aircraft which had been incorrectly bombed-up. In addition there was a suspicion that decoy flares were used by the enemy and were effective in diverting part of the attack. Decoy ground-markers were active during the raid on Bochum on 13/14 May 1943, but here again the primary cause of failure was a gap of 25 minutes in the Oboe marking.(2) The timing of the Oboe aircraft was also poor on the Barmen raid of 29/30 May and although, owing to the heavy weight of the attack, great damage was inflicted, a proportion of the raid was scattered in open country to the south of the town,(3) nevertheless, of the 566 aircraft reporting attack, it was estimated that 82 per cent bombed within three miles. On the heavy raid on Dusseldorf on 11/12 June the main force attack was opened by specially selected crews of Nos.1 and 5 Groups who dropped full incendiary loads. These were well placed and were exceptionally successful in starting fires which spread rapidly and formed an unmistakable beacon for the following aircraft. Approximately 1000 acres of industrial and residential damage resulted from this raid.(4)

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(1) 'Interim Report on the Attack on Cologne, 26/27 February 1943.' Bomber Command O.R.S. Report No. B.126. (A.H.B./IIH/241/22/12).
(2) 'Attack on Bochum, 13/14 May 1943.' Bomber Command O.R.S. Report No. B.138.
(3) 'Report on the attack on Wuppertal, 29/30 May 1943.' Bomber Command O.R.S. Report No.
(4) 'Attack on Dusseldorf, 11/12 June 1943.' Bomber Command O.R.S. Report No. B.142. (A.H.B./IIH/241/22/12).

During the period of these raids only two Oboe channels (i.e. two pairs of ground stations) were available. Moreover, the serviceability of the Oboe aircraft at this time was low, only 66 per cent of sorties dispatched making successful attacks.(1) In view of this situation the greatest difficulty was experienced in maintaining the Oboe marking over the 40-60 minutes duration of the raid, and, in fact, absolute continuity of primary marking was never achieved during the first five months of Oboe groundmarking. In the above mentioned report, in which a review of the first 20 Oboe groundmarking attacks is given, it was pointed out that the main cause of such diversions of effort as had occurred on these attacks was gaps in the Oboe marking, and the desirability of providing more channels was emphasised. The provision of a minimum of four and if possible eight pairs of ground stations was recommended as a future requirement, and it was suggested that once continuity of the primary marking could be guaranteed, it might be possible to dispense with secondary markers altogether.

The provision of a third Oboe channel in July 1943 did, in fact, result in an immediate improvement in our bombing effort. On the first raid on which three channels were used (Essen 25/26 July 1943) the Oboe marking was almost continuous over a period of 50 minutes (2) and on Remscheid 30/31 July, continuous primary marking was achieved for the first time. (3) Both these attacks were outstandingly successful.

In addition to the Ruhr campaign Oboe was also used during March and April 1943 for attacks on the French Atlantic ports. For these raids, however, only one pair of ground stations was available and the Oboe marking was so sparse that it was probably without appreciable effect on the results of the operations which were, in any case, very successful.(4)

It is of interest to compare the overall results achieved against German cities in 1943 by Oboe and H2S respectively. The following statistics, prepared by the O.R.S., but previously unpublished, are based on an analysis of night photographic evidence for raids between April 1943 and April 1944.

Table

Estimates of percentage of those aircraft reporting attack which bombed within three miles of the aiming point for attacks on German and Italian cities between April 1943 and April 1944.

/Technique ....

(1) 'The Operational Use of Oboe Mark IA'. Bomber Command O.R.S. Report No. S.102. (A.H.B./IIH/241/22/14).

(2) 'Attack on Essen, 25/26 July 1943'. Bomber Command O.R.S. Report No. B.154. (A.H.B./IIH/241/22/12).

(3) 'Attack on Remscheid, 30/31 July 1943.' Bomber Command O.R.S. Report No. B.157. (A.H.B./IIH/241/22/12).

(4) 'Operational Use of Oboe Mark IA'. Bomber Command O.R.S. Report No. S.102. (A.H.B./IIH/241/22/14).

Technique	Location of Target	Good Weather	Moderate Weather
Oboe Groundmarking	Germany	66%	59%
H2S Newhaven	Germany	62%	-
H2S Newhaven	Italy	84%	-
H2S Blind Groundmarking	Germany	51%	37%

It will be seen that for raids in good weather on German targets the results achieved by the use of Oboe were only slightly better than those of the H2S Newhaven technique. The great disadvantage of the latter technique however was that it could only be carried out in good weather: in moderate weather conditions such attacks normally reverted to H2S Blind Groundmarking, the results of which were far inferior to those produced by Oboe Groundmarking. The outstanding success of the series of Newhaven attacks on Italian cities during July and August 1943 is attributable partly to the weak defences of these targets and partly to the fact that the weather conditions prevailing were almost always exceptionally favourable for visual identification of the target.

Use of Oboe against Tactical Targets

On 8/9 September 1943 an experimental attack was carried out on coastal batteries in the Boulogne area with a view to investigating the possibility of using Oboe for marking very small targets, and to compare the relative accuracy of Oboe and Baillie Beam Groundmarking, i.e. (aircraft tracking along a Baillie Beam and releasing on Oboe). A special analysis of this operation was undertaken (1) in which it was shown that the line of error of the target indicators dropped by aircraft flying on the Baillie Beam was of the order of 1000 yards, which was far larger than was acceptable for precision marking of small targets of this type. Attention was also drawn to another very serious source of error in Oboe marking: namely, the fact that target indicators released in salvo from high flying Mosquitoes very frequently fell in the form of a stick, sometimes as much as a mile in length. This phenomenon was later established as being due to ballistic interference between the target indicators of a salvo and on subsequent attacks was overcome by releasing the markers with a spacing of 0.25 seconds.

During the months of March-October 1944 the main effort of the Command was diverted from the strategic bombing of German cities to attack on tactical targets in north France, the Low Countries and later in Germany itself. In this series of attacks, where the small size of the targets necessitated marking techniques of high precision, Oboe played a leading part, and to it, more than to any other factor, can be attributed the success of the campaign. O.R.S. work on the marking and bombing of tactical targets is described below.

Oboe-led Formation Attacks by Day

This bombing method, which was designed by No. 8 Group for use against small precision targets, was introduced operationally on 11 July 1944, and was employed at frequent intervals until 5 August. During this period

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(1) "Attack on Coastal Targets at Boulogne, 8/9 September 1943." Bomber Command O.R.S. Report No. B.173. (A.H.B./IIH/241/22/12).

32 attacks were made, consisting of from one to four formations, and involving 688 sorties. All the objectives attacked were flying-bomb launching sites or stores, situated along the coastal strip of northern France.

The formations employed consisted of one Oboe Mosquito plus one reserve, leading from six to 16 'heavies', which were either arranged in pairs in line astern, or in vics. of three or according to a combination of these patterns. In the shorter formations the heavies were instructed to release on seeing the Oboe leader's bombs. In the longer formations aircraft at the rear were to release on coming abeam of a smoke puff which was fired by the Oboe leader at bomb release.

Analyses of the results achieved by 21 of these formation Oboe attacks were made by the O.R.S. from density counts or crater plots prepared from post-raid cover. The results of these analyses were published early in August (1) and clearly demonstrated that for day operations on small targets this formation method was markedly superior to the Oboe groundmarking techniques which had preceded it. Taking the density of bombing in a 20-acre circle about the aiming-point, per 1000 bombs despatched, as a criterion of efficiency, it was shown that Oboe formation raids were 1.85 times as efficient as Oboe groundmarking attacks.

This conclusion was supported and amplified in a later report (2) in which a comparison was made between all the techniques used against precision targets in the spring and summer of 1944. The only serious rival to the Oboe formation method (with 7.4 hits/acre/1000 bombs dropped or 6.1 hits/acre/1000 bombs despatched) was shown to be the later modification of No. 5 Group's visual night technique which achieved densities about three-quarters as great. It was concluded that the choice between these 'rival' methods should be governed by the weather (amount of cloud expected), intensity of defences, scale of attack required and the chance of being able to make a second or third attempt in the event of an initial failure.

On the basis of the parameters obtained from these analyses, an attempt was made by O.R.S. No. 8 Group, with the assistance of one officer from O.R.S., Headquarters Bomber Command, to assess the value of this formation technique for use against synthetic oil plants in western Germany. In preparing these estimates the following assumptions were made:-

(a) Each formation would consist entirely of Mosquitos (no heavies) and would contain an average of 10 aircraft (including two Oboe aircraft).

(b) Four (and occasionally five) Oboe Channels would be available.

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(1) 'Note on Success of Oboe Formation Attacks.' Bomber Command O.R.S. Report No. B.219. (A.H.B./IIM/91/4a)
(2) 'Summary of Analysis of Day and Night Raids on all small targets in occupied territory between March and September 1944.' Bomber Command O.R.S. Report No. S.192. (A.H.B./IIH/241/22/14).

(c) The attacks would be carried out from between 26,000 feet and 28,000 feet over 10/10ths cloud.

(d) The target would require approximately one ton per acre throughout the target area to put them out of action.

On the basis of these assumptions it was concluded that during the winter months, eight to ten of the oil plants could be put out of action in any one month, or alternatively that 15 to 20 plants could be partly put out of action.

No survey of the accuracy of this forcecast could be made since the method was, in fact, never used against this type of target. It was, in fact, employed on only one subsequent occasion (against Wesel, 16 March 1945).

The Operational Use of Gee-H

Early Gee-H Operations

The history of the introduction and development of Gee-H in Bomber Command is dealt with in detail in Chapter 12 and attention will here be confined to ~~[illegible]~~ the efficiency of the tactical methods used and the overall success of Gee-H raids as compared with other types of attack.

The tactical advantages conferred by the use of Gee-H were considerable; since its accuracy was far greater than that of Gee and, at the same time, it was free from the serious limitation in the number of aircraft which could be controlled by a single ground station, which was a feature of the Oboe system. The great potentialities of the device were well shown by the results of the first blind Gee-H bombing attack on 3 November 1943. The target was the Mannesmannrohrenwerke on the northern outskirts of Dusseldorf and although the raid was only on a small scale the accuracy achieved was considered very satisfactory. A bombfall plot prepared by the O.R.S. showed that the 50 per cent zone was of the order of 750 yards. In spite of the success of this attack no further use was made of Gee-H until April 1944 when five small scale experimental and calibration raids were carried out against the marshalling yards at Chambly and Vilvorde.(1) During June and July of the same year Gee-H was used for minelaying, and, during July and August, for daylight attacks on flying bomb sites in northern France. The latter attacks were carried out by Stirlings of No. 3 Group using the new technique of Gee-H formation bombing. Two Gee-H aircraft (leader and deputy) were usually detailed to lead a formation of eight other non-Gee-H aircraft flying in pairs line astern. Each pair of aircraft would release their bombs on seeing the bombs leave the pair immediately in front of them. From a study of the photographs taken on these operations it was found possible to identify the

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(1) "The Performance of Gee-H April 1944," Bomber Command O.R.S. Report No. S.152. (A.H.B./IIH/241/22/14).

bomb strikes of nearly every aircraft in the formation, and also to plot the relative positions of the aircraft in the formation at the moment of release of the leader's bombs. The results of this investigation showed that the performance of the Gee-H aircraft was highly satisfactory, the average error of 275 yards being of the same order as that achieved on training runs in this country. The following aircraft, however, obtained very poor results due to extremely bad formation keeping. This was especially marked on the first two attacks, but later showed some improvement, and was clearly due to the lack of practice in formation flying.(1)

Large scale Gee-H Formation Attacks

Up till this time all the raids on which Gee-H had been used were in the nature of small scale experimental attacks, designed to discover the potentialities of the equipment and the best methods of using it operationally. By October 1944, however, a considerable force of No. 3 Group Lancasters had been equipped, and the middle of the month saw the start of a series of relatively large scale Gee-H attacks directed against synthetic oil plants, towns, marshalling yards, and similar targets in North-west Germany. The total number of aircraft dispatched on these raids was usually between 100 and 200, and the attacks were continued at the average rate of three to four per week until the end of the war. The vast majority of these raids were formation attacks carried out in daylight, many of them over 10/10ths cloud, but on a few occasions Gee-H aircraft were used as ground or skymarkers, and occasionally forces consisting entirely of Gee-H aircraft were dispatched to bomb blindly, without markers or followers.

On Gee-H formation attacks between a quarter and a third of the total force were equipped with Gee-H. The aircraft were detailed to fly in vics. of three or five, or in boxes of four, each vic or box being led by a Gee-H aircraft. Surplus non Gee-H aircraft, if any, were detailed to fly in a gaggle behind a normal vic. In addition, the Gee-H aircraft usually dropped target indicator markers, skymarking flares or coloured smoke puffs for the benefit of stragglers who lost formation and had to bomb independently. The Gee-H leaders would normally release their bombs blindly on their special equipment and the other aircraft in the formation would release immediately on seeing the leader's bombs fall.

Analysis of Gee-H Operations

This technique of bombing was something quite new as far as Bomber Command was concerned, and consequently much effort during the winter of 1944-1945 was devoted to investigations of raids of type. Many analyses were carried out with a view to determining the accuracy of the method, establishing parameters which could be used in forward planning, and if possible, suggesting tactical improvements whereby /success

(1) A.H.B./II/39/1/1 (Bomber Command O.R.S. Rept. No. S.183).

success might be increased. The analyses were based chiefly on plots of estimated position of bombfall prepared by plotting forward from the centres of the release point photographs as described on page 31. For those raids carried out over 10/10ths cloud this technique could not be applied though a considerable amount of information on the dispersion of such raids was obtained from plots of aircraft relative to cloud patterns, prepared by 'N' Section of the Allied Central Interpretation Unit.

The bombs dropped blindly by the Gee-H formation leaders were found to have a 50 per cent zone about the aiming point of 1038 yards, or about the mean point of impact of the bombs of 964 yards, and the dispersion of all the bombs dropped, including those of the followers, was not appreciably greater than that of the Gee-H aircraft.(1) By way of comparison with other types of attack it may be mentioned that the concentration of bombing achieved on an average Gee-H formation attack at this time was about the same as that achieved on night Newhaven attacks against German cities. The Gee-H raids however had a considerable advantage in that the concentration of bombing was far more accurately centred, the average systematic error being only 375 yards, as compared with 1,000 yards for Newhaven attacks. In addition the Gee-H raids were, of course, virtually independent of weather conditions provided that the cloud tops were not higher than 17000 feet, whereas Newhaven attacks, being dependent on visual marking of the aiming point, could only be carried out in reasonably clear conditions.

It was estimated that, using the Gee-H formation bombing technique, a force of 80 to 90 aircraft could achieve a density of 180 tons of mixed H.E. and incendiaries per square mile, which, on a German city, would correspond to about 75 per cent devastation in the area where the attack fell. On most of the Gee-H attacks on German towns almost double this number of aircraft was sent and it is therefore not surprising that almost all these attacks were outstandingly successful. In particular Bonn, Solingen, Witten and Wesel, all suffered extremely heavy damage as a result of attacks of this type.

The density of bombing required to knock out a synthetic oil plant or a marshalling yard for any length of time was three to four times that required to devastate a built-up area and it was estimated that using the Gee-H formation technique a force of approximately 250 Lancasters would be necessary. This was in excess of the number normally dispatched against targets of this type with the result that the density of bombing achieved was usually below that specified, and the required level of damage was rarely achieved on the first attack.

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(1) An Analysis of Gee-H Raids, October to December 1944. Bomber Command O.R.S. Report No. S.211. (A.H.B./IIH/241/22/14).

In general, this investigation, which covered the results of the first 38 Gee-H raids between 18 October 1944 and the end of the year, showed that in spite of the successes achieved there was still room for further improvement, particularly in regard to:-

(a) The accuracy of the Gee-H aircraft. The probable error zone of 1038 yards compared unfavourably with the 640 yards found for Gee-H groundmarking raids. (1)

(b) The elimination of gross errors. As many as 20 per cent of the Gee-H aircraft were estimated to have made errors of more than 2500 yards. (2)

(c) Better formation flying. The average distance between the leaders bombs and those of the other aircraft in the formation was 564 yards, but in addition there were 26 per cent of cases, classed as gross errors, where the follower's bombs fell more than three to four miles from those of the leading aircraft.

As a sequel to this work a further analysis was undertaken of Gee-H formation attacks during the early months of 1945, and this revealed that a considerable improvement had in fact taken place. The 50 per cent error was found to have fallen to 874 yards and the gross errors had been reduced to eight per cent. It was concluded that these improvements were due principally to better handling of the equipment and to the improvement in formation flying which had resulted from continued practice.

Analysis Of Attacks On Tactical Targets

O.R.S. work on Tactical Bombing.

During 1944 Bomber Command was called upon to assist with preparations for the liberation of Europe, and during the spring and summer of that year almost the whole of its bombing effort was diverted from the strategical bombing of German cities to attacks on tactical targets in northern France and Belgium, and later in Germany itself. During March and April many attacks were carried out on the French marshalling yards, and during subsequent months the range of targets was extended to include gun batteries, airfields, ammunition dumps, road junctions, military camps and troop concentrations etc.

With the exception of the daylight attacks by No. 2 Group in 1941 and 1942, the Command had specialised since the beginning of the war in night attacks on large targets such as cities, and the sudden change over to the bombing of small tactical targets, much of it carried out in daylight, presented many new problems, to the solution of which O.R.S. made substantial contributions. These contributions may be summarised under four main headings as follows:-

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(1) "The Accuracy of Gee-H Groundmarking, November 1944." Bomber Command O.R.S. Report No. S.199. (A.H.B./IIH/241/22/14).

(2) "An Analysis of Gee-H Raids, October-December 1944." Bomber Command O.R.S. Report No. S.211. (A.H.B./IIH/241/22/14).

(a) Planning of operations, particularly recommendations as to the size of the force necessary to achieve the required level of damage.

(b) Post raid analysis, to determine how closely the achieved results compared with those required and with those forecast.

(c) Comparison of different marking techniques, with a view to determining the best technique for use against any particular target under different conditions of attack.

(d) Assessment and improvement of marking accuracy.

The planning of operations and the closely linked work on post-raid analysis will be fully described in Chapter 6, and much of the work on the assessment and improvement of marking accuracy is dealt with in Chapter 5. Attention will here be confined chiefly to the research which was carried out into the relative efficiency of the different marking techniques used. Before doing this it will be necessary to give a brief account of what these techniques were and how they were developed.

Marking Techniques used on Tactical Targets

At the beginning of the campaign no special marking techniques, other than those used for night attacks on German cities were available, and the majority of the earlier attacks on marshalling yards and gun batteries were carried out using straightforward Oboe groundmarking. Owing to the relatively short duration of the attacks backers-up were usually dispensed with, but in other respects the method was essentially the same as that used on city targets in the Ruhr. Later a Master Bomber and a Deputy Master Bomber were introduced to control the attack, their original function being to direct the bombing on to the most accurately placed Oboe marker. To enable them to do this it was necessary to illuminate the target with flares for a short period at the beginning of the attack, and for the different Oboe aircraft to drop markers of different colours or types. Where necessary the Master Bomber would himself mark the target visually with target indicators of a distinctive colour. A further development of the Controlled Oboe technique was Musical Newhaven (or No.8 Group Visual) where the Oboe markers were dropped very early in the attack, and were intended to serve only as a guide to the flare force, who would then illuminate the target for the visual markers, as on a standard Newhaven attack.

In addition to these techniques, which were used by the Pathfinder Force, No. 5 Group developed a special visual marking method employing low-level offset marking. In the technique as originally used a single marker was laid by a special crew upwind of the target at a distance of about 400 yards from the aiming point. Its actual distance and bearing from the target was estimated by the Master Bomber, who, using the winds found by a special force of aircraft equipped with Air Position Indicators, would calculate a false wind, such that bombs aimed correctly at the marker would fall on the aiming point. This false wind was then broadcast to the

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Main force just before they reached the target area. A few targets were also marked by No. 1 Group, who used a much simpler controlled visual marking method, employing impact bursting target indicators backed-up with red spot fires.

During the first three months of the campaign against tactical targets all the bombing was by night. Day attacks started in June 1944 when they accounted for 17 per cent of our bombing effort, and this percentage continued to rise until September, when day raids accounted for 70 per cent of all the sorties dispatched. The technique used on these day attacks were, in many cases, similar to those used at night, a large proportion of attacks being carried out using Oboe or controlled Oboe Groundmarking. Formation attacks led by Gee-H (see page 81) or Oboe (see page 78) aircraft were also employed, and on some attacks direct visual bombing of the target was used.

Comparison of different techniques used on Tactical Targets

The first attempt to assess the relative efficiency of the above mentioned techniques was made in May 1944, for a series of night attacks on railway facilities in France and Belgium. As a criterion of the success of each raid, which would be independent of the size and geographical position of the target, the ratio of the number of hits achieved on the target area, to the number expected, was used. The latter was estimated from the number of bombs dispatched by multiplying by the 'expected percentage on', the calculation of which is explained in a Bomber Command internal O.R.S. memorandum.(1)

Over a series of 15 Oboe groundmarking attacks the number of hits achieved on the primary target amounted to 57 per cent of the number expected. For five Musical Newhaven raids the percentage was 64 per cent, for six Controlled Oboe groundmarking raids, 79 per cent, and for three Visual groundmarking attacks carried out by No. 5 Group, 93 per cent. The beneficial effect of the Master Bomber was clearly reflected in the better results achieved using Controlled Oboe, as compared with non-controlled Oboe groundmarking.(2) This investigation, which was intended only to give a preliminary indication of which techniques were likely to give the best returns on future attacks, was severely criticised by No. 8 Group, who, unwilling to admit the superiority of No. 5 Group's marking technique, maintained that the attacks selected for analysis were unrepresentative. The results were also criticised by No. 5 Group on the ground that they were based on crater plots, and therefore depended to some extent on the proportion of craters which could be recognised on day cover. They claimed that, since this proportion was likely to be lower for No. 5 Group attacks, their results were actually better than the report indicated.

In order to meet these and other criticisms, data was collected for a much more extensive analysis along the same lines. The results of

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(1) 'The method of estimating the scale of attacks on marshalling yards using Oboe ground marking, 8 April 1944'. Bomber Command O.R.S. Memo. No.

(2) 'A Comparison of the marking techniques used on marshalling yard attacks'. Bomber Command O.R.S. Report No. S.154 (A.H.B./II/69/231(B)).

this investigation, covering 207 precision attacks, were published.[1] The factor used as a quantitative measure of success was 'relative density at the aiming point' (i.e. hits per acre at the aiming point per 1000 bombs dropped). The count of the number of hits was actually made from the P.R.U. cover, over a 20 acre circle centred on the aiming point, as explained on page 34. The raids were classified, not only according to technique, as in the earlier investigation, but also according to weather, target defences, height of attack, bomber group, and size of raid, and in assessing the value of a particular technique, the proportion of abortive and partially abortive raids, and the loss rate, was taken into account. The coefficient of variability (100 s/m, where s = standard deviation of relative densities, and m = mean relative density) was employed as a criterion of 'dependability' - an important factor against certain types of tactical targets, such as troop concentrations, where repeat attacks were often not possible.

The results of this investigation, which were extensive, are summarised in tabular form in O.R.S. Report S.192, and will not be dealt with in detail here. It should, however, be noted, that the superiority of No. 5 Group's visual marking technique for night attacks on small targets, which the earlier results had suggested, was fully confirmed, the relative density of 5.43 hits/acre/1000 bombs being more than double that achieved by any other technique. In addition, the coefficient of variability (57.7 per cent) was considerably lower than that for raids carried out by other groups using Oboe or visual groundmarking. Further investigation showed that the explanation of this high average density lay chiefly in the smaller systematic error of the No. 5 Group attacks (average 175 yards compared with 312 yards for other groups), and this in turn was attributable to the precision of their low-level visual marking technique (See page 84).

By day, the highest relative densities were achieved by Oboe formation attacks, which have already been discussed (page 78). This type of attack, however, in spite of its high efficiency, suffered from serious limitations which prevented its more widespread use by the Command. Thus, only comparatively small-scale attacks were possible and the number of abortive or partially abortive raids due to failure of the Oboe leaders, was high (25 per cent). In addition, these small formations proved very vulnerable to flak when clear conditions were encountered over the target.

In addition to the above investigations a short analysis was carried out in May 1944, at the request of Bomber Command Air Staff, of the results of 28 attacks on gun batteries in northern France[2] with a view to determining which would be the best technique to use against these targets on the night prior to the D-day landings. The amount of data available at this time, however, was not sufficient to come to any firm conclusions, and although

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(1) 'Summary of Analysis of Day and Night Raids on all small targets in occupied territory between March and September 1944.' Bomber Command O.R.S. Report No. S.192. (A.H.B./IIH/241/22/14).

(2) 'A Preliminary Analysis of Attacks on Gun Batteries,' 30 May 1944. Bomber Command O.R.S. Memo. No. 106. (A.H.B./IIH/241/22/3).

it seemed that under clear conditions No. 5 Group's visual technique would probably give the best results, it was recommended that, in view of the uncertainty as to the amount of haze which would be encountered, Controlled Oboe groundmarking would be the safest method to employ.

CHAPTER 4

THE STUDY OF DAY BOMBING TECHNIQUES, 1940 TO 1943 AND MISCELLANEOUS INVESTIGATIONS INTO BOMBING OPERATIONS

Attacks on Ships

Low-level attacks on Ships at Sea

On 12 March 1941 Blenheims of No. 2 Group, then attached to Bomber Command, commenced a series of low-level daylight attacks on enemy coastwise shipping, an offensive which reached its peak in April and was maintained until October of the same year. During this period, for a total of 2320 sorties dispatched, 72 ships of tonnages varying from 50 to over 8000 were sunk, a further 65 seriously damaged and 63 slightly damaged.(1) The ships attacked were mostly merchant and cargo vessels whose positions were the subject of definite intelligence, and reporting vessels, which constituted the forward posts of the enemy raid warning system, whose position was known only approximately. The majority of these attacks took place off the enemy coast between Boulogne and Heligoland, with a smaller number off the southern tip of Norway and along the west coast of France between Brest and St. Nazaire.

At this time there was little information available, either on the accuracy of bombing to be expected from such attacks, or on the most efficient tactical methods to employ. It was even considered doubtful whether the damage inflicted on the enemy was sufficient to justify the wastage rate, which during the summer of 1941 continued to rise steadily, until by October it had reached the high value of 35 per cent of the sorties attacking. It was in order to answer questions of this kind and to provide data which would be of value in planning future operations of this type that the O.R.S., at the request of Sir Henry Tizard, undertook an extensive analysis of these anti-shipping attacks, based principally on the evidence from strike photographs taken by the attacking aircraft and on crew interrogation. Use was also made of data supplied by the Ship Damage Assessment Committee. A preliminary statistical survey covering operations from March to August 1941 showed that on the average 21 per cent of the sorties dispatched found and attacked their targets, that 42 per cent of these attacks resulted in damage to the ship, and that 22 per cent of the attacking aircraft became casualties.(2) These results compared very favourably with those achieved by Coastal Command on similar attacks, but the percentage of ships attacked which were sunk

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(1) 'Review and Analysis of Low Level attack on ships by aircraft of No. 2 Group, Bomber Command, during the period 12 March – 31 October 1941.' Bomber Command O.R.S. Report No. 40. (A.H.B./IIK/46/46B).

(2) 'Low Level Attacks on Enemy Shipping.' Bomber Command O.R.S. Report No. S.6.

or seriously damaged was somewhat less than that achieved by the enemy in his attacks on our own coastal shipping during the same period.(1) In Bomber Command O.R.S. Report No. 40 (2) more extensive data, covering the period from March to October, were given, and the effort, cost and results of the attacks were considered in relation to the tactical methods used. Amongst other things these investigations served to dispel certain impressions which until that time were generally held; in particular, the belief that the chance of hitting a ship was increased by making two attacks, and that losses could be reduced by attacking at mast height, were not substantiated. The probability of hitting a ship of 2,500 tons from a height of 200 feet was found to be 0.13 from which it was estimated that the average error of bombing was of the order of 50 yards. This accuracy was of the same order as that achieved by No. 2 Group in pre-war practice bombing, and is one of the very few cases where the standard of accuracy achieved on the bombing range has been maintained under operational conditions. (See Page 103).

After October 1941 the main responsibility for the anti-shipping offensive was taken over by Fighter and Coastal Commands and No. 2 Group was largely diverted to land targets. They continued, however, to operate on a reduced scale against ships, both at sea and in dock, throughout 1942 and details of all these attacks are to be found in the series of 'Day Raid Reports', written and published by the O.R.S. between February 1942 and July 1943.

Attacks on Ships at Night

Comparatively few night attacks against ships at sea have been carried out by Bomber Command. During May and June 1942, 96 such sorties were made, chiefly by Blenheims, Hampdens and Wellingtons, but a short analysis made by the O.R.S. (3) confirmed that these attacks were almost entirely unsuccessful, none of the ships being sunk and less than one per cent seriously damaged. This type of attack was subsequently discontinued.

Attacks on Shipping in Dock

Quite early in the anti-shipping campaign the question arose as to whether it was more profitable to attack merchant ships at sea or in dock. As very few of the latter type of attack were carried out, however, it was not until July 1942 that sufficient operational data

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(1) Bomber Command File B.C./S.26627, Encl. 5A.
(2) 'Review and Analysis of Low Level Attack on ships by aircraft of No. 2 Group, Bomber Command, during the period 12 March - 31 October 1941.' Bomber Command O.R.S. Report No. 40. (A.H.B./IIK/46/46B).
(3) 'Bombing of Shipping at Night, 1 May 1941 to 30 June 1942.' Bomber Command O.R.S. Memo. No. 150.

had been collected to attempt to answer this question. Even then the data were not extensive, only 90 low-level and 235 medium level sorties having been despatched. The indications were, however, that mast-height attacks against concentrations of shipping in dock, although costly in aircraft, were considerably more economical from the point of view of tons sunk per aircraft lost than were similar attacks against ships at sea.(1) Medium-level operations (7,000-13,000 feet) on the other hand were found to be most uneconomical against this type of target, few ships being sunk and a high casualty rate sustained by the attacking aircraft.

Attacks on Capital Ships

A great deal of theoretical work was done, both in this country and America on the best tactics to use and the chance of success in high level attacks on ships, particularly capital ships, and a useful summary of the problems involved and the main conclusion reached, as they affected Bomber Command, will be found in O.R.S. Report B.223.(2) In this paper use was made of theoretical data presented in a report by M.A.P. (R.D. Inst.7a), and operational data on bombing accuracy obtained by a study of attacks on land targets, and an attempt was made to estimate the number of bombs to be aimed for a 50 per cent chance of a direct hit on a ship of the Tirpitz class, using either the Stabilised Automatic Bombsight or the Mark XIV Bombsight. As it was not possible with the Mark XIV to make allowance for target speed the O.R.S. undertook, at the request of the Command, to calculate the necessary aiming-ahead allowances for ships of various sizes and speeds. These allowances, given as a multiple of the ship's length, were published in O.R.S. Memorandum No. 94,(3) and were later re-issued as a Bomber Command Armament Training Note.

Day Attacks on Land Targets

General Account

During the months of July to September 1941 a series of high-level day bombing attacks was carried out by Fortress aircraft of Bomber Command, but the main daylight offensive did not start until early the following year. This offensive, directed against enemy factories, shipbuilding yards, power stations and transport facilities was carried out mainly by Bostons of No. 2 Group, though later in the campaign, Mosquitoes, Mitchells and Venturas gradually replaced the Bostons. Aircraft of Nos. 1, 3, 4 and 5 Groups also participated, the latter in particular being responsible for many of the larger

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(1) 'Attacks on Shipping in Dock, 1 May 1941 to 30 June 1942.' Bomber Command O.R.S. Memo. No. 151.

(2) 'Attack on Ships.' Bomber Command O.R.S. Report No. B. 223. (A.H.B./IIH/241/22/12).

(3) 'A Comparison of Various Types of Day Bombing Operations, 28 February 1943.' Bomber Command O.R.S. Memo. No. 94. (A.H.B./IIK/46/46B)

scale day attacks such as those on Danzig, Le Creusot, and Milan. This offensive continued until the end of May 1943, when No. 2 Group was transferred to Fighter Command, and it was not until June 1944 that any further daylight bombing was undertaken by the Command.

During this period a special study was made by O.R.S. of these daylight operations and, in addition to the routine series of 'Day Raid Reports' which were produced, a number of detailed investigations were carried out into the relative effectiveness of the different tactical methods employed, with particular reference to such features as height of attack, cloud cover and fighter escorts and formation versus non-formation flying. These investigations were based chiefly on the analysis of strike photographs taken by the attacking aircraft, supplemented by crew interrogation and intelligence reports. In assessing the success of a particular type of operation use was made of the concept of Efficiency which was defined as the percentage of bombs dispatched which fell on the primary target, and Economy which measured success in relation to wastage rate and was defined as the number of aircraft bomb loads falling on the primary target per aircraft lost.

Apart from certain special operations the majority of the daylight raids undertaken during this period fall into one of several well defined classes which are discussed in the following paragraphs.

Circus Operations

Attacks of this type were always carried out in clear weather at heights varying from 8-14,000 feet. The bombers, which were Boston III's normally flew in close boxes of six, each box being covered by a close escort wing of three squadrons of fighters flying 100 to 3,000 feet above them. Still higher flew the escort cover wing whose function was to prevent surprise attack on the close escort, and finally all the formations were guarded by a high cover wing flying at still greater height. The primary object of these missions was to raise and engage that portion of the Luftwaffe fighter strength then based on the Western front. It was thereby hoped not only to prevent their transference to the Eastern theatre but to impose a higher wastage rate than could conveniently be borne. Previous experience had shown that enemy fighters were much more likely to oppose an operation on which bombers were involved than one in which fighters alone were employed, and the main role of the Bostons was that of 'decoy' to the German 'game'. A secondary object of the raids, however, was to cause damage to important objectives in enemy territory and it was this aspect of the raids which chiefly engaged the attention of the O.R.S. at Bomber Command.

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The bomb-aiming on these operations was done by the leader of each vic of three using the Mark IX course setting bombsight, and the average radial error of the centroids of the bomb patterns from each vic was found to vary from 200 yards to 520 yards depending on the amount of opposition.(1) On the basis of these figures it was estimated (2) that Circus operations were the most efficient type of daylight raid, but only for targets exceeding 800 yards in radius, which was considerably larger than the usual type of target which was being attacked at that time. They were, on the other hand, extremely economical, even on quite small targets, as the protection afforded by the very strong fighter escort reduced bomber losses to a low level (1.8 per cent). At the same time the fighter escort imposed serious limitations both on the range and on the scale of the operations, and in view of this it was improbable that this type of attack would ever play more than a comparatively small part in our day bombing offensive.

Low level Operations.

This type of operation was also carried out mostly by Boston III's whose limited range of 500 miles confined them to targets in northern France and Holland, though on some occasions longer range targets were attacked at low level by Mosquitoes and Lancasters. The bombers flew towards the enemy coast at sea level, approached their targets at low altitudes and attacked usually from less than 100 feet. The operations were generally carried out without the assistance of fighter cover, though on some occasions the withdrawal of the bombers from the target area was covered by a fighter screen patrolling five to 15 miles off the enemy coast. The majority of the raids were carried out in clear weather by aircraft operating in formation, though a smaller number were made by aircraft operating singly or in loose pairs, often making use of low cloud to avoid interception <u>en route</u> to and from the target.

These operations were, on the whole, very successful, and although the number of sorties involved was small judged by later standards (only 400 were dispatched over a period of 15 months between July 1941 and October 1942), appreciable damage was inflicted on power stations, factories, docks and similar objectives in Holland, France, Germany and Norway. Analyses of these raids (3) showed that although losses were high (17 per cent) the raids were very efficient and, for attacks on small targets, more economical than most types of day raid from the point of view of bombs on target per aircraft lost.(4) In Bomber Command O.R.S. Report No. S.71 the effects of cloud cover, fighter escort

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(1) A.H.B./IIK/46/46B.
(2) 'A Comparison of Various Types of Day Bombing Operations', 28 February 1943, Bomber Command O.R.S. Memo. No. 94. (A.H.B./IIK/46/46B).
(3) 'Low Level Operations in Daylight', Bomber Command O.R.S. Report No. S.71. (A.H.B./IIH/241/22/14).
(4) A.H.B./IIK/46/46B.

and formation versus non-formation attacks are discussed both in relation to bombing efficiency and wastage rate, though in view of the somewhat small number of sorties involved it was not possible at that time to come to very firm conclusions regarding the influence of these factors.

High-level bombing

The small scale Fortress raids of July to September 1941 were mostly made by single aircraft of No. 90 Squadron, and were largely in the nature of experiments in high altitude flying. Although unable to reach the stratosphere, the Fortresses operated in the upper regions of the atmosphere at altitudes varying from 27,000 to 35,000 feet and by doing so hoped to avoid fighter interception - the principal cause of high losses in daylight operations. This hope, however, was not realised, for of the 48 sorties dispatched nine were intercepted and two were shot down.(1) Neither was the bombing particularly accurate, for, in addition to the great difficulty in finding and seeing the aiming point, the Sperry O1 bombsight with which the aircraft were equipped was not adapted for heights above 20,000 feet and could not be used as a fully automatic sight. Moreover, numerous technical defects associated with high altitude flying were encountered, the most important of which were overheating of the engines, icing, and the formation of condensation trails. These, together with bad weather and various minor technical defects were responsible for the very high rate of abortive sorties, 52 per cent of aircraft returning to base without having bombed.

In 1942 a similar series of small scale high-level attacks was carried out by Mosquito aircraft and a comparison between these and the earlier Fortress raids was made by the O.R.S. (2) The Mosquitos operated at lower altitudes (18-25000 feet) and, as a result, had very little trouble from icing and none from condensation trails, so that the proportion of effective sorties was increased to 76 per cent. It was found moreover that the danger of fighter interception was not appreciably increased by the reduction in height.

Although these high-level attacks were on far too small a scale to inflict any appreciable amount of material damage on the enemy, or even to have much indirect value as nuisance riads, they served to demonstrate several important points about high level bombing, viz:

(a) A further increase in height into the stratosphere would be needed if the danger of fighter interception was to be reduced.

(b) Failing the stratosphere it was better to operate at heights below, rather than above, 25000 feet.

(c) That precision bombing from high altitude could not be expected with the bombsight equipment then in use.

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(1) 'Operations at High Level in Daylight.' Bomber Command O.R.S. Report No. S.66. (A.H.B./IIH/241/22/14).
(2) A.H.B./II/70/289.

The lessons learnt from these early experiments in high altitude flying later proved of value when, in December 1942 the Oboe system, necessitating the use of high flying aircraft, came into operational use.

Cloud Cover Raids.

During 1942 a small but persistent effort in cloud-cover raiding was maintained, mostly by Wellingtons of No. 3 Group, though Hampdens, Lancasters and Mosquitos from other Groups also participated. Aircraft were dispatched singly in thick medium cloud, which had to be continuous, or nearly so, until the target was reached, when the aircraft broke cloud and bombed from below cloud base. Each aircraft was either given a specific target, or, in the true 'Moleing' operation, a roving commission to attack any target of importance seen on breaking cloud cover. These operations were chiefly intended as nuisance raids, the primary object of which was to harass the enemy warning system and cause loss of production through interruption of work. Their bombing efficiency was very low indeed, over 50 per cent of sorties being totally abortive, mostly owing to lack of adequate cloud cover, and only one per cent claiming to have bombed their targets visually. The loss rate on the other hand, which was four per cent, was low compared with other types of daylight operations at this time.(1)

From a study of the effect of enemy air activity on production in this country, and from intelligence information on the German raid warning system, an attempt was made to assess the nuisance value of these raids. It was estimated that, although they undoubtedly had a certain potential nuisance value, the rate of operation, averaging less than one sortie per day, was totally inadequate to have any adverse effect on production. It was thought however that a sustained effort of ten to 20 sorties per day might be expected to reduce production in the area concerned by about ten per cent, but in the light of subsequent experience even this appears to have been something of an overestimate.

Special Daylight Operations

From time to time during 1941 and 1942 Bomber Command carried out comparatively large scale daylight raids on special objectives, and as experience of such attacks was at that time very limited, these did not invariably go according to plan. As a result the O.R.S. were sometimes called upon to undertake special investigations into the less successful raids in order to determine the main causes of failure, and to suggest means by which the same mistakes might be avoided in

/future

(1) 'Cloud-Cover Bombing in Daylight.' Bomber Command O.R.S. Report No. S.65. (A.H.B./IIH/241/22/14).

future. Thus, on the dusk attack on the Schneider Works at Le Creusot by 81 Lancasters of No. 5 Group on 17 October 1942, the P.R.U. evidence revealed that the main weight of the attack had overshot on to a neighbouring housing estate and that the works themselves had escaped with comparatively light damage. (See Page 105) Investigation revealed that the principal cause of the failure was the poor visibility due to the failing light, zero hour having been fixed for 15 minutes after sunset. Important subsidiary causes of failure were the incendiaries dropped by the first aircraft over the target, the smoke from which prevented visual identification by the later aircraft, mutual interference between aircraft attempting to bomb at the same time, and misuse of the bombsight.(1) The remedies in this case were fairly clear, and the experience gained on this attack was made use of in planning subsequent operations of similar type.

Investigations were also made into the raid on Augsburg on 17 April 1942, and into the part played by Bomber Command in the combined operations against Dieppe on 19 August 1942. On the latter occasion the bombing of the gun batteries was rendered quite ineffective by the activity of enemy fighters, and although the task of laying smoke screens from low level was successfully carried out, the casualty rate from flak was extremely high. It was pointed out (2) that, unless losses could be reduced it could not be hoped to maintain an offensive of this type for more than a few days with the reserves of aircraft and maintenance staff at that time available. In view of this a complete overhaul of the technique of smoke-laying from aircraft was suggested.

Bombing Accuracy on Daylight Operations

A number of investigations were carried out to ascertain the accuracy achieved under different conditions, using different types of bombsights, some of which have already been referred to. The average radial error of the Mark IX course setting bombsight from a height of 10000 feet when little opposition was encountered was found to be of the order of 350 yards, but the data available was not extensive enough to make any definite statement regarding the variation in bombing accuracy with height of attack. The effect of heavy opposition was to double the bombing error (3).

A preliminary investigation into the accuracy achieved with the Norden bombsight from 25,000 feet during August 1942 showed that the average radial error was of the same order as that achieved by the Mark IX course setting bombsight from 12,000 feet.

(1) 'Bombing Accuracy in Daylight Raid on Le Creusot.' Bomber Command O.R.S. Report No. S.76. (A.H.B./IIH/241/22/14).
(2) 'A Note on the Losses sustained at Dieppe.' Bomber Command Memo. No. M.
(3) 'A Preliminary Note on Bombing Accuracy in Daytime.' Bomber Command O.R.S. Report No. 41. (A.H.B./IIK/46/46B).

Miscellaneous Investigations

Investigations into the use of Decoys by the Enemy

The elucidation of the structure, location and methods of use of decoys by the enemy was primarily the responsibility of the decoy section ('Q' Section) at the C.I.U., but in so far as such decoys were factors liable to influence the success of operations they came within the purview of O.R.S. Moreover, the observations of 'Q' Section were based entirely upon photographic interpretation, whereas those of the O.R.S. depended on operational evidence, particularly sortie raid reports and plots of night photographs. It is consequently a matter of some satisfaction that these two quite independent lines of investigation led, in the main, to essentially the same conclusions.

Decoy Activity during 1941 and 1942.

During 1941 and 1942 the principal type of decoy used by the enemy at night was the fire site. These sites were readily recognisable on day cover and were described in a series of 'Q' reports issued by the C.I.U. They were seen to consist of groups of walled enclosures filled with combustible material which, when ignited, produced the effect of a group of burning buildings. These decoy fires were often recognised in action on night photographs by the close and regular light tracks which they produced, and numerous instances occurred where they were effective in diverting a considerable proportion of the attack. Thus on the raid on Essen on 25/26 March 1942, 15 of the 36 photographs plotted were concentrated just north of Rheinburg, about 20 miles West north West of the target and showed decoy fires burning.(1) This decoy site was not previously known, but its position was later confirmed from day cover of the area. Similarly 40 per cent of the photographs taken on the Cologne raid on 27/28 April were plotted in the neighbourhood of the Haumar fire site, seven miles South-east of Cologne, which was in action on this night.(2) Many other references to diversions of effort caused by fire sites will be found in the early reports of the 'B' Series and in the Night Raid Reports dealing with operations during 1942.

Evidence of Decoy Flares and Groundmarkers

With the introduction, in January 1943, of skymarking flares and the target indicator marker bomb, our aircraft ceased to bomb on fires, and the fire site consequently lost much of its effectiveness. The enemy was thus forced to modify his decoy system, and as early as February 1943 it was suspected that he might be using decoy skymarker flares.(3) Suspicions that he might also be making attempts to

/simulate

(1) 'Attack on Essen 25/26 March 1942.' Bomber Command O.R.S. Report No. B.107. (A.H.B./II H/241/22/12).
(2) 'Attack on Cologne, 27/28 April 1942.' Bomber Command O.R.S. Report No. B.110. (A.H.B./II H/241/22/12).
(3) 'Interim Report on the Attack on Cologne, 26/27 February 1943.' Bomber Command O.R.S. Report No. B.126. (A.H.B./II H/241/22/12).

stimulate our target indicator markers were first aroused as a result of an analysis of the raid on Stuttgart on 11/12 March 1943.[1] During the final stages of this raid only a single salvo of green target indicators were burning. Nevertheless at least 37 aircraft bombing during this period claimed to have had red target indicators in their bombsight, and these aircraft were all plotted in an area well to the south-west of the target. There was no evidence available at this time to show whether these aircraft had in fact been deceived by an enemy decoy or had simply mistaken a fire burning in open country for a red target indicator marker, but in the opinion of the O.R.S. the former was the most likely explanation, as discrepancies of this nature had not been observed on previous raids.

More definite, although admittedly still controversial evidence, of decoy indicator markers was obtained for the raid on Bochum on 13/14 May 1943. On this raid, owing to Oboe failures, there was a gap of 25 minutes in the middle of the raid when it was quite certain that no red target indicators were dropped by our own aircraft or were burning on the ground. Yet 118 aircraft, or 40 per cent of all those attacking during the gap in the marking, claimed to have bombed on red target indicators. A still more important point was that 33 crews reported seeing single red target indicators cascading during this period.[2] In view of these facts arrangements were made by the O.R.S. for the re-interrogation of all crews who claimed to have bombed on red target indicators during this period and various members of the O.R.S. attended some of the re-interrogations in person. The great majority of crews confirmed that they actually had the red target indicator in the bombsight at the time stated and they were confident that they had not mistaken fires for red target indicators. Throughout this and subsequent investigations the inherent unreliability of the crews' reports was borne constantly in mind, but in this case it was considered most unlikely that such a large number of crews, including some of considerable operational experience, should have been mistaken as to what they saw in the target area. There was, on the other hand, the evidence of the Senior Air Staff Officer of No. 3 Group, reproduced as Appendix B in Report No. B.137 who himself flew in this raid and was over the target for a period of five minutes during the gap in the marking. He claims to have seen nothing during this period which could possibly have been mistaken for a red target indicator marker, and this conflicting evidence cast a certain amount of doubt on the conclusions reached. As a result of this investigation certain recommendations were made by the O.R.S., the chief of which were:-

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(1) 'Interim Report on the Attack on Stuttgart, 11/12 March 1943.' Bomber Command O.R.S. Report No. B.131. (A.H.B./IIH/241/22/12).

(2) 'Report on Investigation into Possibility of Decoy Red T.I.s, Bochum on 13/14 May 1943. Oboe Groundmarking.' Bomber Command O.R.S. Report No. B.137. (A.H.B./II

(a) That crews should be warned of the possible existence of dummy target indicators.

(b) That as many new operational crews as possible should be given the opportunity of seeing the displays of target indicator markers arranged by the Pathfinder Force over this country, before taking part in operations.

Much evidence of a similar nature to that obtained on Bochum continued to accumulate during the summer of 1943. Particular examples will be found in many of the reports in the 'B' Series of Bomber Command O.R.S. reports and a summary of the principal raids on which decoy activity was suspected was given in a Bomber Command O.R.S. Internal Memorandum. In order to get more detailed information on the nature and method of use of these decoys the O.R.S. drew up a pro-forma to be filled up by experienced and reliable crews who, on Newhaven attacks, saw target indicators of the primary colour (i.e. as used by the visual markers) after Z plus 10 minutes. As the target indicators dropped by the visual markers had almost invariably burnt out by Z plus seven at the latest any target indicators of this colour seen after this time would almost certainly be of enemy origin. From an analysis of these questionnaires and from a study of night photographic evidence it was concluded that these decoys were in the nature of rockets fired from the ground, which burst in the air and cascaded to the ground in a shower of coloured candles in the same manner as our own target indicator markers, the principal difference being that the burning time of the candles was shorter, the number of candles fewer, and the colours less bright. These decoy indicators were thought to be shot up singly at fairly frequent intervals during the raid and to be used chiefly though not entirely in the neighbourhood of established fire-sites. It was observed that the fire-sites themselves were often, though not always, in action at the same time as the decoy markers. On some raids the use of decoy fire sites and decoy markers was observed to be associated with the use of smoke screens in open country (e.g. Cologne 3/4 July 1943). These conclusions were at first received with considerable scepticism particularly by the Pathfinder Force and by 'N' Section of the C.I.U. whose objections were based chiefly on the fact that at that time decoy target indicators had not been recognised with certainty on night photographs.

Study of Day-cover

Meanwhile, however, the Decoy Section ('Q' Section) at the C.I.U., working quite independently and on evidence of an entirely different nature, had come to essentially the same conclusions as the O.R.S. In Report QS.2 (1), published in November 1943 they suggested that certain /emplacements

(1) A.C.I.U. Int. Rept. No. QS.2, 25th Nov. 1943.

emplacements which began to appear in the neighbourhood of German fire sites during the months of June to August 1943, contained firing pieces which might be used for firing decoy target indicator devices. Two basic types of emplacements were discovered, referred to as the 'A' and 'B' types. The 'A' type structures were circular whereas the 'B' type, which were found only in the Berlin area, were rectangular emplacements divided internally by cross walls. Continued study of day cover showed a sequence of simplification in these sites and, about the middle of 1944, certain non-emplaced sites in open country were interpreted as decoy target indicator layouts. It was not until September 1944 that decoy target indicators were recognised on night photographs by 'N' Section A.C.I.U. with any degree of certainty although several cases of suspected decoy target indicators on night photographs had been reported by the O.R.S. before that time. (1)

Ground-survey of Decoy Sites

Direct confirmation of the above conclusions regarding the nature and use of decoy markers was not obtained until the Spring and early summer of 1945 when ground surveys of the sites became possible. Towards the end of April a decoy site near München Gladbach was visited by the Armament Officer of No. 8 Group, who confirmed that the decoy target indicators were in the nature of large rockets fired from the ground, and who brought back the first description of the decoy target indicator rocket and firing piece. Photographs of a similar site near Mayen were also published in April 1945 by the Office of the Chief Ordnance Officer, Headquarters, European Theatre of Operations, U.S. Army. At the beginning of June 1945 two members of O.R.S. accompanied representatives of Colonel Sir John Turner's Department and 'N' Section, A.C.I.U. on a visit to the decoy sites in the Mannheim and Frankfurt areas. In all eight sites were visited and, in spite of extensive demolition by the enemy and further damage sustained in the subsequent fighting, sufficient evidence was found to reconstruct the main features of the sites and the equipment used, though certain details still remained obscure. The results of this visit are described in detail in Bomber Command O.R.S. Report S.224 (2) and, in general fully confirmed the conclusions reached by the O.R.S. and by 'Q' Section in 1943. On six of the eight sites visited devices for simulating target indicator markers both in the air and on the ground were found, and the existence of decoy flares was also confirmed. The conclusions of 'Q' Section regarding the nature and use of the 'A' type structures were also proved to be correct. Unfortunately little documentary evidence was discovered which might have given a clue as to the date on which decoy markers and flares were first employed, or as to the raids on which they were used.

/Effect of ....

(1) 'Observations on enemy T.I. Markers, 14 April 1944.' Bomber Command O.R.S. Memo. No. 66.

(2) 'Report on the Decoy Sites in the Mannheim and Frankfurt Areas with particular reference to Decoy T.I. Devices.' Bomber Command O.R.S. Report S.224. (A.H.B./IIH/241/22/14).

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Effect of Decoy Target Indicators on Operations

Although the use by the enemy of decoy marker bombs was undoubtedly a factor, and, on some occasions a very important factor. in influencing the success of our attacks, the overall effect on our bombing offensive was by no means as great as it at one time threatened to become. As a result of detailed analyses of most of the major area attacks in 1943 the general conclusion was reached that decoy target indicators were most effective under conditions when, owing to technical failures or to unexpected weather conditions, the marking technique did not go according to plan. Thus, although on a number of raids a high proportion of the main force did undoubtedly bomb decoy markers, these, in general, could only be considered secondary rather than a primary cause of failure. Whenever the weather was good and the marking technique carried out according to plan, the enemy decoys had little success, at the most causing some scattered bombing around the edge of the target.

The enemy decoy system remained active throughout 1944, but had even less effect on our bombing than in 1943. Although it is likely that they attracted a proportion of the bombing on some of our small scale Mosquito attacks, their effect on major operations was usually negligible. That this was so can probably be attributed to the following factors:-

(a) Improvement in our own marking techniques.

(b) The shortening of the duration of raids.

(c) The use of the Master Bomber.

(d) The fact that the enemy decoy target indicator markers were rather a poor imitation of our own, and that he seems to have made no attempt to improve on his earlier efforts. As a result the more expert crews soon became expert in recognising decoy target indicators and in distinguishing them from the genuine article.

(e) The fact that aircrews were warned of the existence of decoy markers and were kept informed as to their probable appearance and method of use, and on the best method of distinguishing them from our own markers. Several paragraphs along these lines were included in 'Methods of Target Marking', a publication prepared by the O.R.S. for the use of aircrews, and more detailed information on the Berlin decoys was given in Bomber Command O.R.S. Report B.222. (1)

Effect of Experience on success in Target Location

Early Investigations

The first attempt to assess the effect of the operational experience of the aircrew as a factor influencing the success of target location was made by O.R.S.4 in June 1942. All the captains

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(1) Memo. for Operational Crews on Decoy T.I.s in the Berlin Area; Bomber Command O.R.S. Report No. B.222. (A.H.B./IIH/241/22/12)

in No. 3 Group were classified into experience categories according to the number of operations which they had completed, and within each category the number and proportion of photographs plotted within varying distances of the target was determined for a series of operations. The photographic evidence at this time was too scanty to permit any very detailed investigation, and the results obtained did not demonstrate any correlation between experience and success. It was concluded that the effect of experience was probably being swamped by some other more important factor.

Analysis of attack on Kassel, 22/23 October 1943

A detailed investigation of this raid was undertaken in a further attempt to determine the effect of experience on bombing success. This was a very successful Newhaven attack, which took place under clear weather conditions, and the M.P.I. of both the primary and secondary markers remained close to the aiming point throughout the attack. This, combined with the fact that the approximate bombing positions of 338 aircraft were known from the plotted positions of their night photographs, made this raid a particularly favourable one for such an investigation.

It was shown that the distance from the aiming point at which a night photograph was plotted was influenced by the previous operational experience of the captain, and independently, to an approximately equal extent, by that of the air bomber. [1] The relationship was found to be a logarithmic one, so that from the point of view of improvement in bombing performance the experience gained on the first trip of the operational tour was equivalent to that gained on the next two equalled that gained on the next four etc. The second operations showed, on the average, an improvement of five per cent over the first, and thereafter the percentage improvement attributable to successive trips decreased on a logarithmic scale. The magnitude of the correlations demonstrated was small (r between distance of photo from the aiming point and logarithm of the number of operations completed by the Captain = 0.17) and showed that many other factors besides experience were undoubtedly operating.

These results suggested other lines of investigation which might have proved profitable had there been time to follow them up. How for instance, did the proportion of crews in different experience categories affect the concentration of bombing achieved, and to what effect was this factor influenced by fluctuations in the loss rate? A certain amount of data bearing on this question was collected early in 1944, but owing to other more urgent work the investigation was never completed.

(1) 'The Effect of Experience on Bombing Success, 16 March 1944.' Bomber Command O.R.S. Memo. No. 67.

CHAPTER 5

THE ACCURACY OF BOMBING OPERATIONS

The accuracy of Bomber Command attacks varied greatly from raid to raid, but apart from this wide fluctuation which can loosely be called random, there was a steady improvement right through the war. Yet even if the accuracy had remained fixed, the weight of bombs dropped on enemy targets would have shown a marked increase owing to the increasing scale of effort. In other words, one of the parameters of a bombfall distribution, not discussed in Chapter 2, is 'N', the number of bombs (or aircraft in a photo plot) contributing to the distribution, and in monthly or yearly summation 'N' steadily increased. It seems desirable, therefore, that any account of accuracy should be seen against a background of the scale of effort involved.

The Changing Scale of Effort

Probably the simplest way to convey the changes in effort will be by means of time-charts and Figures 1 to 4,(1) drawn from Air Ministry War Room monthly data, are suitable for this purpose. Figure 1, showing total sorties despatched monthly against all targets, is sufficiently arresting with its 200-fold increase from about 100 per month in the early months of the war to a peak of 21,000 per month in 1945. Attention is drawn to the relative decline to a yearly minimum each January.

Figure 2, showing the tonnage of bombs dropped, would be still more arresting were it possible to use a vertical scale large enough to show the 1939 tonnages. Actually, the increase corresponding to that of the previous paragraph was some 80-fold. The reason for this is the gradual conversion from light and medium to heavy bombers, which is reflected in Figure 4 (tons dropped per sorties despatched) itself showing a 40-fold increase from about 0.1 to 4.0 tons per sorties. Another factor contributing to Figure 4 is the decreasing abortive-rate, which explains why this figure also shows a slight winter decline.

Figure 3, showing numbers of mines laid monthly, is a reminder that Bomber Command had other tasks besides dropping bombs. In addition there were many leaflet-raids.

Increasing Accuracy

A detailed investigation into trends in accuracy has not been included in this chapter. Figure 5,(2) showing the percentage of aircraft despatched which bombed within three miles of the aiming point, in good and moderate weather, on night attacks on German area targets, will serve as a rough indication of the trend. Unlike the previous curves, this curve has an upper limit at 100 per cent. To avoid excessive fluctuations running averages over six months have been used. It is not considered that this parameter is adequate at values above 75 per cent where a smaller radius such as two miles or one mile would be better but would alter the

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Monthly totals of sorties despatched against all targets by Bomber Command

September 1939 — April 1945

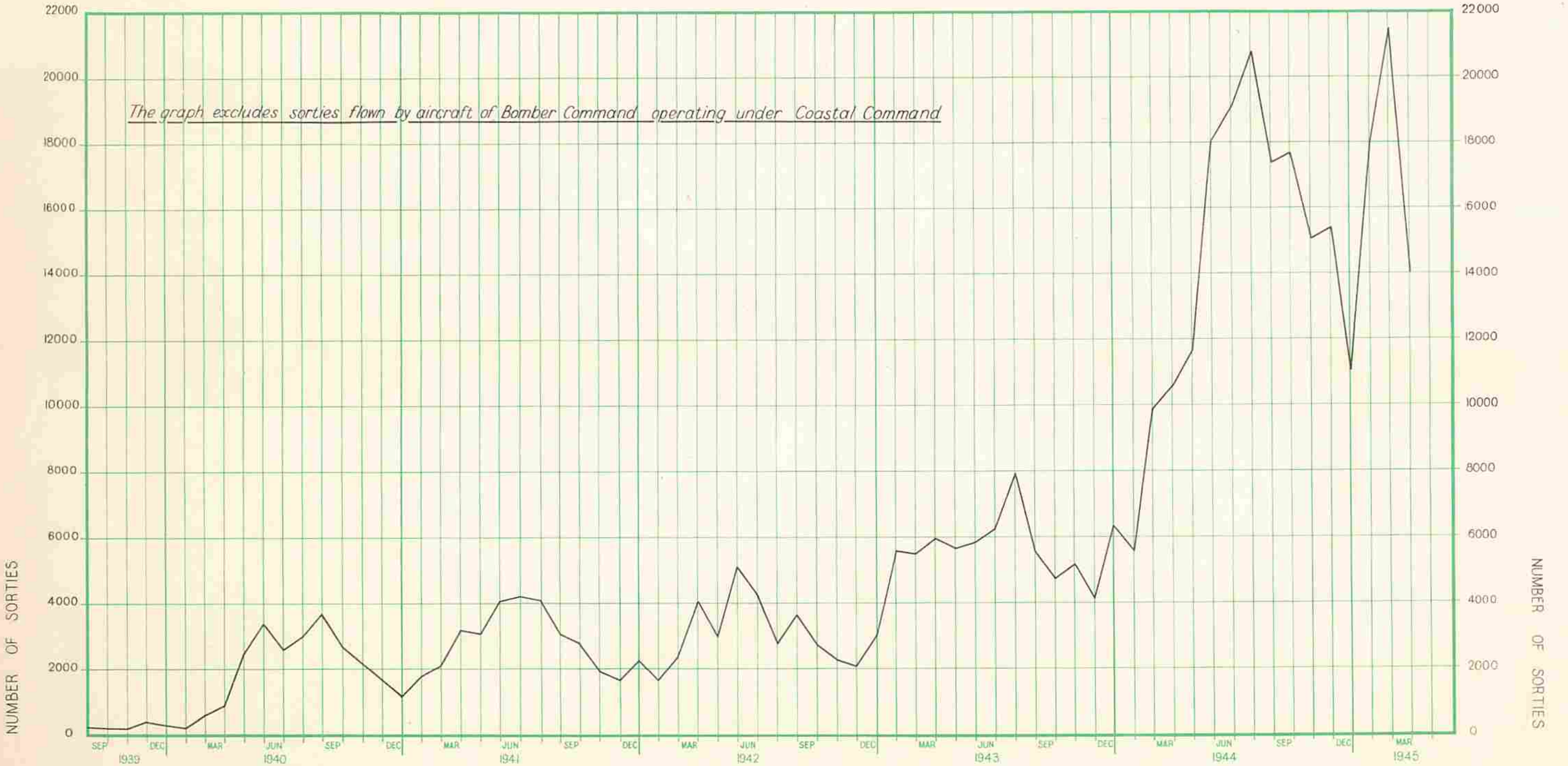

FIGURE I

A.H.B.I. DIAGRAM Nº 1364

Monthly tonnage of bombs dropped on all targets and Germany only by Bomber Command

September 1939 April 1945

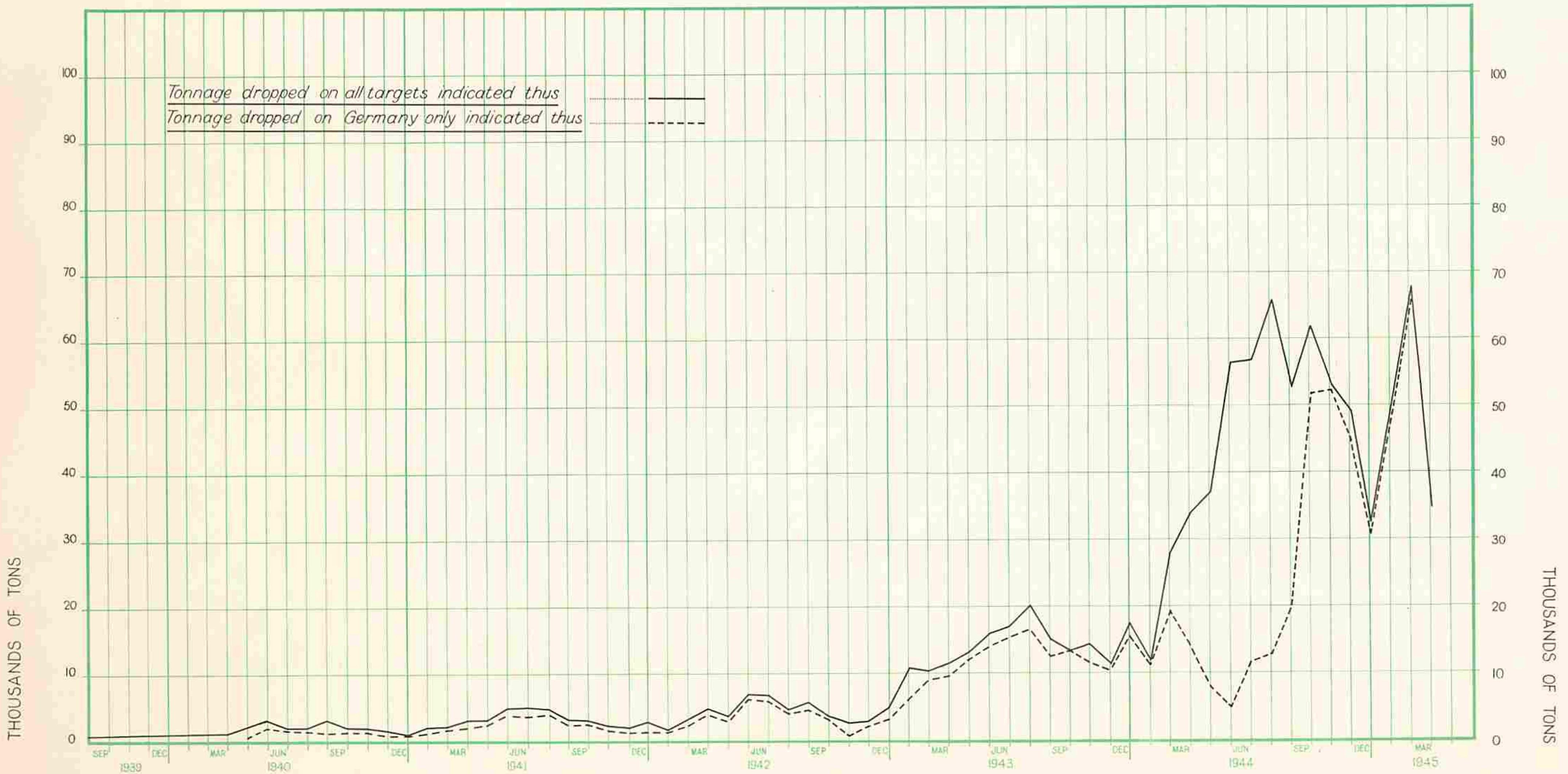

FIGURE 2

A.H.B.I. DIAGRAM Nº 1365

Monthly Totals of Mines Laid by Bomber Command

September 1939 - April 1945

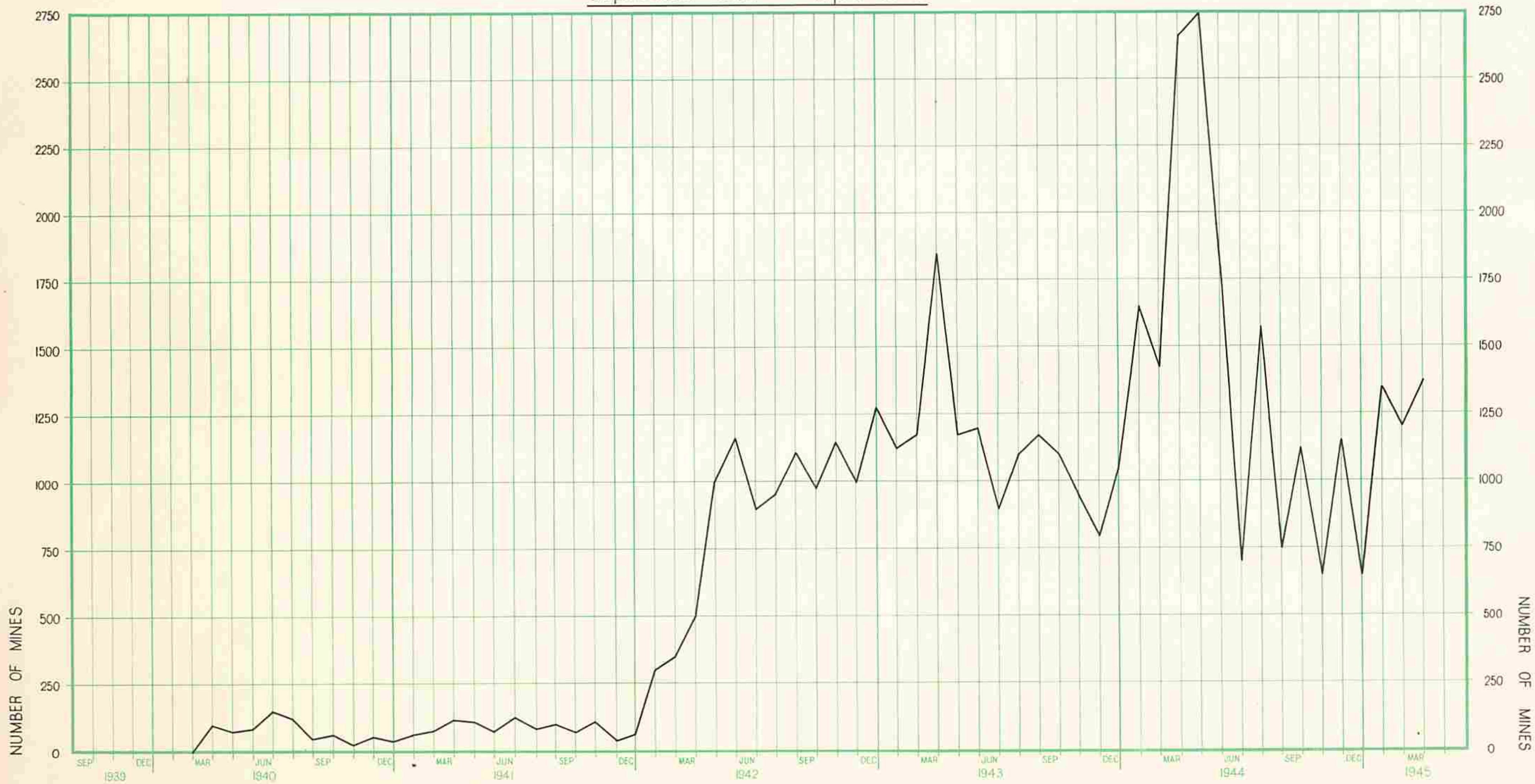

FIGURE 3

A.H.B.I. DIAGRAM Nº 1366

Monthly totals of tons of bombs dropped per sortie despatched by Bomber Command

September 1939 – April 1945

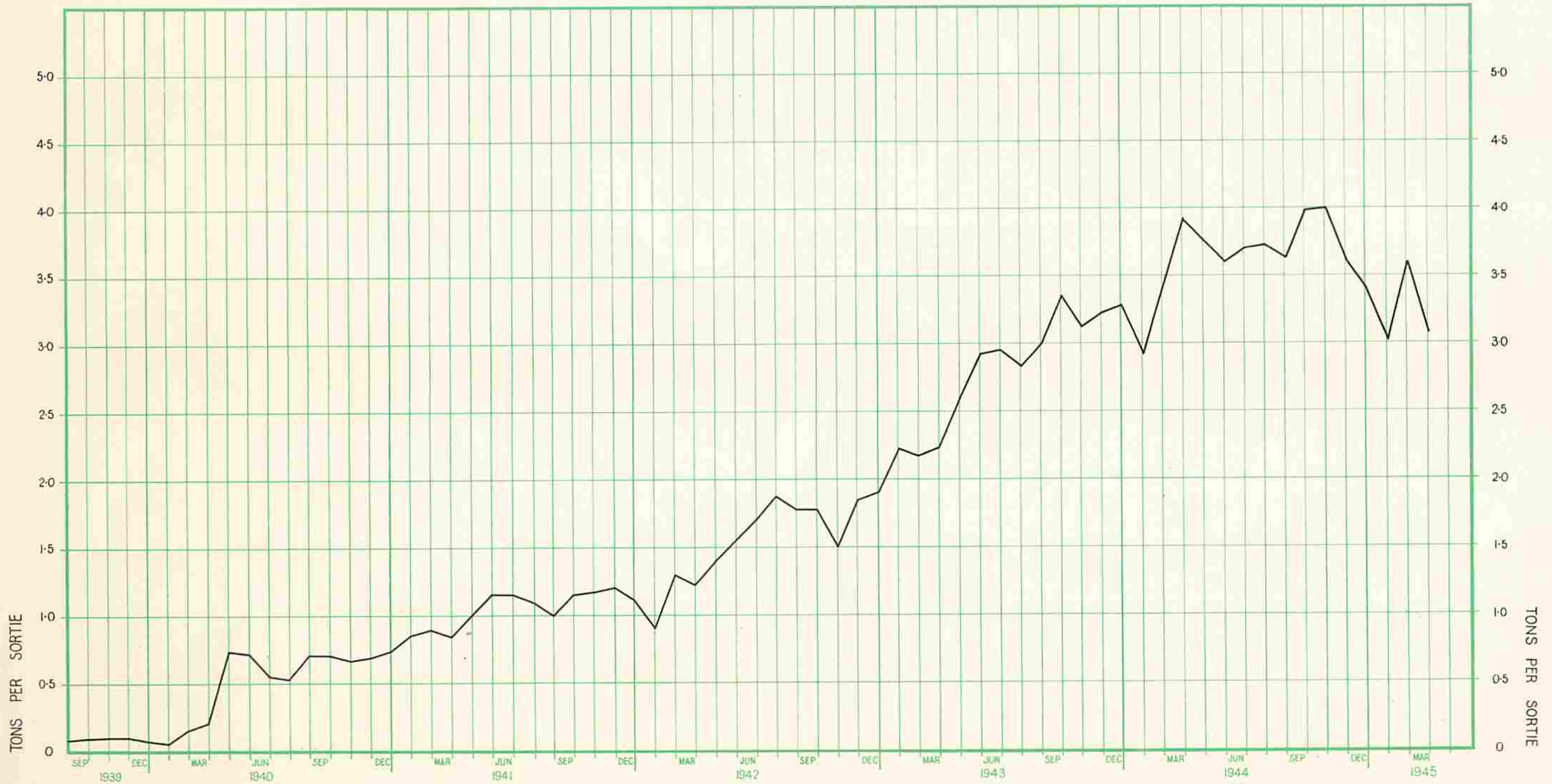

FIGURE 4

A.H.B. I DIAGRAM Nº 1367

ACCURACY OF NIGHT BOMBING OF GERMAN CITIES (EXCLUDING BERLIN)

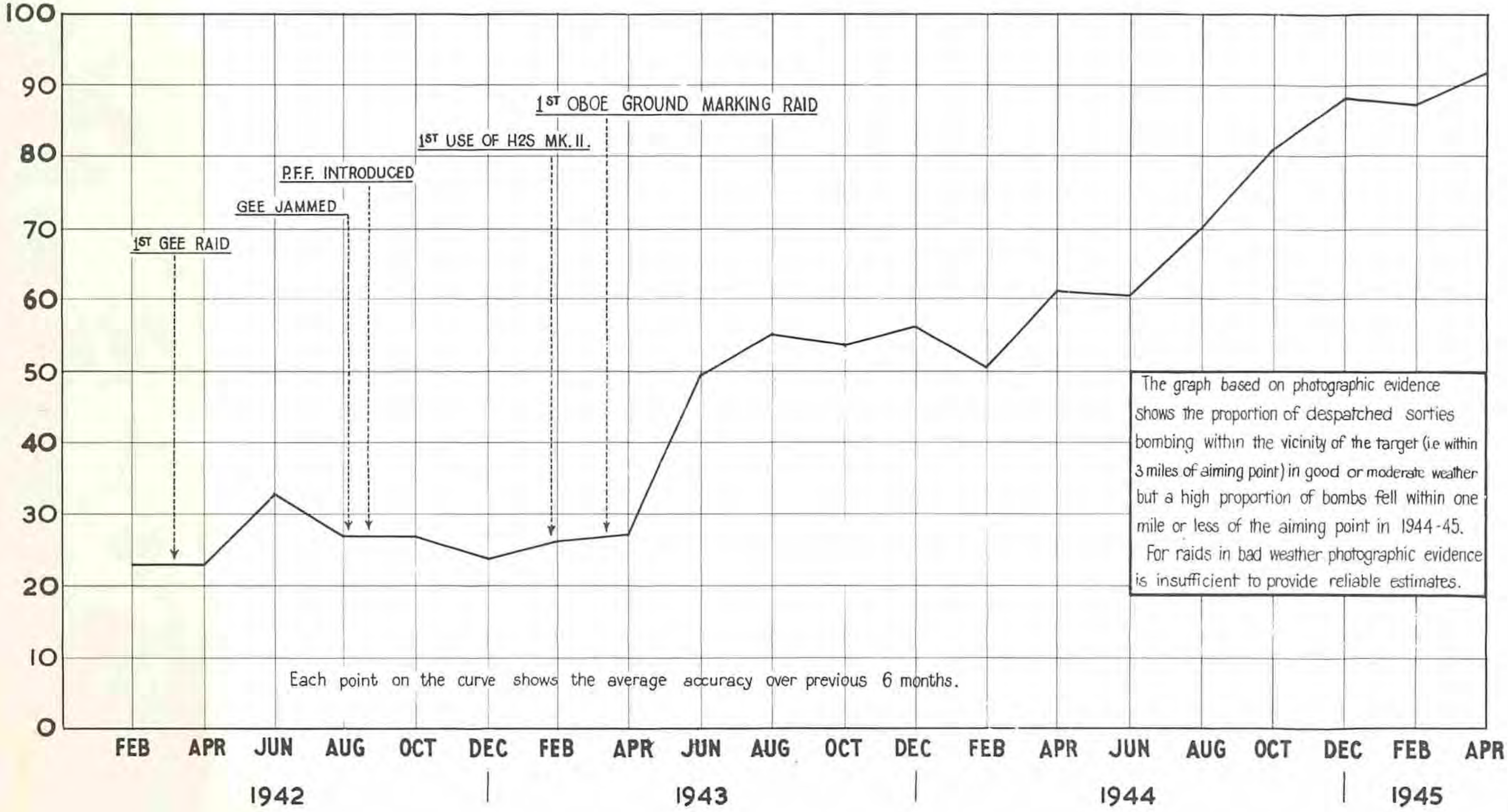

FIGURE 5

A.H.B.I. DIAGRAM Nº 1368

basis of comparison. If data were available for the earlier raids, the point densities referred to above would be the most satisfactory parameter for this purpose.

The accuracy curve should be viewed in conjunction with Figure 1 which, however, includes all targets; the three-mile percentage values would be higher for all targets. Thus the three mile values for April 1943 and April 1945 can be taken as about 30 per cent and 90 per cent respectively, a three fold increase. The corresponding values for sorties despatched are about 6,000 and 21,000, a 3.5 fold increase, so that the absolute numbers of sorties bombing within three miles show an increase of about ten fold.

The increase in accuracy achieved throughout the war against area targets at night was such that whereas before 1943 it was customary to quote the result of a raid in terms of the percentage of aircraft bombing within five miles of the aiming point, by the end of the war the result was assessed by the percentage bombing within one mile of the aiming point. The improvement measured in relation to a one mile radius was even more spectacular than quoted above.

Daylight Operations, 1941 to 1942

Low Level Attacks on Ships

A comprehensive review of the series of low-level attacks on ships carried out by Blenheims of No. 2 Group from March to October 1941 was carried out and published as Bomber Command O.R.S. Report No. 40.[1] (See page 89) In this analysis an estimate of the bombing accuracy was deduced from the probability of obtaining a hit; this probability was calculated from the ratio of hits claimed to bombs dropped. It was found that the probability of hitting increased as the square root of the tonnage of the ship and, using this relationship it was deduced that the probability of hitting for a standard tonnage of 2,500 was 0.13. This corresponded to an average radial error of 50 yards for the average height of 200 feet. This was approximately identical with the pre-war practice bombing results obtained by Blenheims.

Targets in Occupied Territory

The first analysis of bomb accuracy in attacks on land targets covered the period December 1941 to April 1942 and was published as Bomber Command O.R.S. Report No. 41.[2] This dealt only with medium-level, i.e. 6,000 to 15,000 feet attacks carried out in formations of six aircraft with the leader of each vic of aircraft sighting independently and the data used was derived from strike photographs. The attacks were divided into height bands of 2,000 feet width and also divided according to whether much or little opposition was encountered. The analytical procedure employed consisted simply of obtaining the average error in

(1) 'Review and Analysis of Low Level attack on ships by aircraft of No. 2 Group, Bomber Command, during the period 12 March - 31 October 1941'. Bomber Command O.R.S. Report No. 40. (A.H.B./IIK/46/46B).

(2) 'A Preliminary Note on Bombing Accuracy in Daytime'. Bomber Command O.R.S. Report No. 41. (A.H.B./IIK/46/46B).

line and range, and also radially, of the bombs in each class. It was shown that when little opposition was present the line and range errors were approximately equal and the average radial error for a height of 10,000 feet was of the order of 350 yards. The corresponding peace-time practice error was 200 yards. When much opposition was encountered the average radial error was shown to be approximately doubled, the increase in the range error being greater than that in the line error. There was also an indication that the error increased more rapidly with increasing height in the case of attacks against much opposition.

At a later date a complete review of the daylight operations for the first six months of 1942 was published as Bomber Command O.R.S. Report No. [redacted]52.(1) In this a somewhat more refined analysis of the bombing accuracy of medium level attacks was included. ~~In this analysis,~~ The accuracy of ~~an~~ the aiming operation was deduced from the position of the centroid of the group of bombs dropped as a result of that operation and the average errors of those centroids were calculated in preference to the average errors of all bombs pinpointed which was used in the earlier note. At this stage a greater subdivision of the degree of opposition could be made and it was found that against no opposition the average radial error for an average height of 11,000 feet was 200 yards, line and range errors being equal. It will be noted that this value was ~~is~~ equal to the peace-time practice bombing figure quoted in Bomber Command O.R.S. Report No. 41,(2) but that point was not made in the report. In the presence of any opposition whatsoever the average radial error was doubled, the line and range components remaining equal. Against heavy opposition a further increase in the range error took place but there was no corresponding increase in the line error.

Comparison of the results with those quoted in the earlier paper showed that there had been an appreciable improvement in the accuracy against much opposition and this was attributed to increased experience and to improved technique; in particular the introduction of a Bombing Run Start Indicator which enabled the moment for the turn on to the bombing run to be estimated with much greater precision was considered to have had an important effect. This device was developed by No. 2 Group and consisted of a series of lines drawn on the perspex of the aircraft nose in such a way that by sighting the target from the knob at the top of the height bar of the Course Setting Bombsight Mark IX the moment for turn could be estimated. The details of this device which were set out in an appendix to No. 2 Group's Tactical Report [redacted] were sent by the O.R.S. to the Instrument Department of the Royal Aircraft Establishment who acknowledged the usefulness of being kept informed of the current problems of the Service and the expedients adopted for their solution.

/Although

(1) Bomber Cmd O.R.S. Rept No. 52 (Air Min. Science 1 Library).
(2) A.H.B./IIK/10/46B.
(3)

Although No. 2 Group continued to carry out daylight operations of various types until it was transferred away from the control of Bomber Command in May 1943 no further review of bombing accuracy was carried out by the O.R.S. owing to pre-occupation with problems connected with the night bomber offensive which was the Command's most important task at that time. There were, however, a number of special large scale daylight operations carried out during the latter part of 1942 and on one of these, an attack on the armament works at Le Creusot carried out by Lancasters of No. 5 Group on 17 October, 1942, results were disappointing. A detailed study of the bombing accuracy was therefore carried out in an endeavour to arrive at the causes of this ~~and this~~ which was published as Bomber Command O.R.S. Report No. S.76.(1) This investigation revealed that there had been a strong tendency to overshoot the target, the centroid of the bomb pattern lying about 400 yards beyond it. (See page 95) By examination of the raid reports for this operation and discussion with the staff of Headquarters No. 5 Group, it was possible to attribute this result to a combination of causes. Two of these were the failing light, zero hour having been put at 15 minutes after sunset, and smoke from incendiaries dropped early in the raid which together made visual identification very difficult. Another contributory cause was the large number of aircraft going over the target at once and the failure of the force, through lack of practice and experience in this type of operation, to deploy in height and heading as originally planned. Partly as a result of this the heights of aircraft at bombing were in most cases considerably below those laid down, the average discrepancy being 2,000 feet. Since most of the crews were using the stabilised automatic bombsight as a pre-set sight this departure from the briefed height would cause an overshoot of about 350 yards. Last minute adjustments may have been made in many cases but these are likely to have led to inaccurate setting-up of the sight. These points were taken into account in planning future operations of this type.

At about this time a small scale investigation into the accuracy of the first attacks by the American VIIIth Air Force was carried out by O.R.S. Bomber Command to provide information for the Air Staff at Bomber Command on the potentialities of the Norden bombsight with which the American aircraft were equipped and of the tactics of day bombing in comparatively large formations. The note that was prepared was not issued as a report since it dealt with the operations of a force which was not part of the Command, but it has been included in the series of Internal Memoranda as No. M.91.(2)

Night Attacks on German Towns from 1940 to end of 1943

Night raids on German towns down to the end of 1943 or early 1944 fall conveniently into three periods, as follows:

/(a)

(1) 'Bombing Accuracy in Daylight Raid on Le Creusot.' Bomber Command O.R.S. Report No. S.76. (A.H.B/IIH/241/22/14).

(2) 'Accuracy in Daylight Bombing from 25,000 feet, using the Norden Bombsight, 30 September 1942.' Bomber Command O.R.S. Memo. No. M.91. (A.H.B./IIH/241/22/3).

(a) Raids prior to August 1941 (when O.R.S. Bomber Command was first established). Not merely are there no valid analyses for this period, but the basic data are too inadequate in both quantity and quality to sustain analysis. The period is to be thought of in terms of few, small, and ill-equipped aircraft making valiant attempts to damage the enemy's economy, but mostly scattering a small bomb-load over a wide area on each raid, and therefore achieving a negligible density of bombs at the aiming point.

(b) Raids from August 1941 to February 1943. Measures of accuracy become practicable during this period, which is interesting as including the introduction of Gee and (later) of the Pathfinder Force but disappointing in that neither of these events lived up to expectations. The only marked improvement visible in Figures 1 to 5 is the increasing tonnage dropped per aircraft despatched, mainly due to conversion to heavies.

(c) Raids from March 1943 to February 1944. This period marks the vindication of the Pathfinder Force, now equipped with Oboe and H2S and using target indicator markers, and includes both the spring and early summer campaign against the Ruhr, using Oboe, and the later H2S campaign against targets outside of Oboe coverage, starting with the series of raids on Hamburg.

Nothing further can usefully be said on the subject of the first period, but the other two merit separate treatment.

August 1941 to February 1943

This period ~~is~~ was surveyed over all targets in an O.R.S. report, ~~called 'A review of night bombing operations over a period of 19 months, August 1941 to February 1943',~~ written in March 1943, but not generally published. ~~[illegible]~~ It ~~has~~ was ~~recently been~~ eventually published as Report No. M.63 [1]. This report covered 316 raids and some 38,000 sorties and used as a parameter the percentage within three miles of the aiming point, supplemented by another which is a true measure of dispersion: percentage within three miles of the centre of the concentration. It recognized three distinct sub-periods, briefly dealt with below.

Pre-Gee Period to March, 1942

In this period, with 65 sorties per raid and 68 per cent of the despatched reporting attack, 20 per cent of despatched sorties bombed within three miles of the aiming point (averaged over 147 raids). There is also a dissection by geographical area, by weather (good, moderate and poor), and by moonlight (bright and dark), but it should be noted that this is in terms of attacking sorties which bombed within three miles of the aiming point. These values of the latter parameter for German towns are relevant.

Coastal towns:	33%	of attacking sorties within three miles of aiming point.
Ruhr towns:	14%	
Other inland towns: .	23%	

/Gee Period: ...

(1) A Review of Night Bombing Operations over a Period of 19 months, August 1942 to February 1943. Bomber Command O.R.S. Memo. No. 63. (A.H.B./IIH/241/22/3).

Gee Period: March 1942 to August 1942

In this period, with 148 sorties per raid and 75 per cent of the despatched reporting attack, 24 per cent of despatched sorties bombed within three miles of the aiming point or 32 per cent of attacking sorties (averaged over 103 raids). The data for German towns are:

	Percentage of attacking sorties within three miles of the Aiming Point	Centroid
Coastal towns:	44%	47%
Ruhr towns:	11%	13%
Other inland towns:	29%	33%

Thus, raids became larger, and the abortive-rate declined; moreover, the above table shows that raids were well centred, since the three-mile values about the aiming point and the M.P.I. were not widely discrepant. But, whilst Gee appeared to have had some beneficial effect on most German raids, those on the Ruhr showed no improvement.

Early Pathfinder Force Period: August 1942 to February 1943

In this period (omitting the highly successful Italian raids), with 214 sorties per raid and 82 per cent of the despatched reporting attack, 24 per cent of despatched sorties bombed within three miles of the aiming point or 29 per cent of the attacking sorties (averaged over 50 raids). The data for German towns are:

	Percentage of attacking sorties within three miles of the Aiming Point	Centroid
Coastal towns:	27%	39%
Ruhr towns:	34%	39%
Other inland towns:	18%	42%

Although raids were still larger and with even fewer abortive sorties, there was no improvement in accuracy except in the Ruhr.

The discrepancy between the aiming point and centroidal three mile percentages, particularly marked in the case of the more distant targets, clearly underlines the point already made above: the effect of the Pathfinder Force was to increase the concentration of a raid at the expense of introducing a systematic error. Raids were no longer so widely scattered about their M.P.Is. but, also were no longer centred on the target. For any given size of target, and a systematic error exceeding the target radius, there was a lower limit to the random error below which further concentration would put fewer bombs on the target. This problem of the systematic error (some theoretical aspects of which were discussed in Bomber Command O.R.S. Report No. 124 (1) constantly engaged the attention of O.R.S. from this time onward.

/The

(1) 'The Technique of Raid Analysis and Forward Planning.' Bomber Command O.R.S. Report No. 124. (A.H.B./II/39/1).

The advent of the Pathfinder Force coincided with the jamming of Gee which made the device almost useless over Germany. Moreover, the Pathfinder Force was learning its difficult job and, in this period, had inadequate tools for carrying it out. The period at the end of 1942 and the first two months of 1943 marks a crucial point in the development of Bomber Command. Along with a continuing rise in the ratio of heavies to others and a notable increase in the number of aircraft operational (see Figures 1 and 2),[1] there came almost simultaneously the first operational use of Oboe and H2S, and of target indicator markers leading to the highly satisfactory ground-marking techniques. The effect of these three devices is plainly to be seen in the sudden increase in accuracy during 1943, reflected in Figure 5.[2]

March 1943 to February 1944

While it is true that the 1943 Oboe raids against the Ruhr and H2S raids against more distant targets were of an altogether higher order than earlier attacks, and, for almost the first time inflicted very serious damage on the enemy's towns, it is also true that they still left a great deal to be desired in that they were often badly centred, too dispersed, and of a marked elliptical shape. All these faults were to a large extent corrected later in 1944, but they were very obvious to those studying them in 1943 and they led to the detailed time-analysis of raids described on page 47. This type of analysis initiated the use of standard Gaussian parameters for measuring photo plots, a use which was continued to the end of the war. The parameters will be used in the present section to calculate point-densities as measures of accuracy, though the three percentages will also be quoted for comparative purposes. Finally, factors affecting accuracy which were brought to light and measured by time analysis will be touched on.

The Spring Oboe campaign against the Ruhr, 1943

In an analysis of eight of the major raids in this campaign it was found that on the average there were 657 sorties per raid and 86 per cent of the despatched reported attack. 60 per cent of despatched sorties bombed within three miles of the aiming point, or 70 per cent of the attacking sorties. The latter figure should be compared with the 34 per cent relating to the Ruhr towns above. Moreover, 30 per cent of attacking sorties bombed within the zoned target area. The mean area of the 50 per cent zone (ellipse or circle) centred on the M.P.I. was 7.46 square miles and the mean offset of the M.P.I. (systematic error) was 1.70 miles.

The calculated density at the aiming point (see below for details of individual raids) averaged 63.4 tons per square mile or, in relative form, 37.2 tons per square mile per 1000 tons dropped.

(1) Facing Page

(2) Facing Page

The Autumn H2S Campaign against distant Towns, 1943

Detailed analysis was carried out on nine of the major raids in this campaign, as a result of which it was found that on the average there were 604 sorties per raid and 87 per cent of the despatched reported attack. 48 per cent of despatched sorites bombed within three miles of the aiming point, or 55 per cent of the attacking sorties. The latter figure should be compared with the 18 per cent related to other inland towns on page 107 and with the 70 per cent for 1943 Ruhr raids. It will be seen, although H2S raids were decidedly less accurate than Oboe raids on this showing, they nevertheless trebled the figure for the type of target concerned, whereas Oboe raids merely doubled the Ruhr figure. Here again, 30 per cent of attacking sorties bombed within the zoned target area, but the targets were larger on the average. The mean area of the 50 per cent zone centred on the M.P.I. was 9.19 square miles and the mean systematic error was 2.29 miles. Thus, these H2S raids were both more scattered and less well centred than the Oboe raids.

The calculated density at the aiming point averaged 51.4 tons per square mile or, in relative form, 31.5 tons per square mile per 1000 tons dropped.

Aiming-Point Densities

Since they are not available elsewhere, it may be useful to list the absolute and relative aiming-point densities for the individual raids analysed, the eight Oboe raids being given first and the nine H2S raids second. As has been explained on page 44, the calculated density at the aiming point is a valuable and steady parameter which is independent of heterogeneity with the distribution and makes use of all the data. This calculated density is given in the left hand columns of the table below for the 17 raids on German cities in 1943 and, on the right hand columns by way of comparison, for a further 17 raids in 1944 and 1945. The density is given in two forms; the absolute density, in tons per square mile at the aiming point, which takes into account the scale of the attack, and the relative density, in tons per square mile at the aiming point per 1000 tons dropped, which is independent of scale of attack and strictly measures relative accuracy including both centring and scatter.

It will be seen from Table No. 1 that in terms of absolute density a rate of 57 tons per square mile at the aiming point was averaged in 1943, with a range from 3.2 to 216 tons per square mile. The corresponding figures for 1944/45 were 219 tons per square mile on the average, with a range from 23.7 to 658 tons per square mile; thus the average was nearly four times as great. In terms of relative density the 1943 average was 33 tons per square mile per 1000 tons dropped and in 1944/45 it showed a five-fold increase to 174. The 1944/45 data included two daylight raids, in order to be representative, but even excluding these there was an increase in accuracy at night to a value of 122.4 tons per square mile per 1000 tons dropped or 3.7 times the 1943 accuracy.

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TABLE No. 1

DENSITY AT THE AIMING POINT - GERMAN CITIES

(Calculated from Raid Parameters)

TARGET	DATE	ABSOLUTE DENSITY (tons/ sq.mile)	RELATIVE DENSITY (per 1000 tons dropped)	TARGET	DATE	ABSOLUTE DENSITY (tons/ sq.mile)	RELATIVE DENSITY (per 1000 tons
Duisburg	26/27-4-43	8.5	5.9	Stuttgart	25/26-7-44	159.1	110.2
"	12/13-5-43	53.4	36.6	Hamburg	28/29-7-44	48.9	42.4
Bochum	13/14-5-43	21.0	21.1	Russelsheim	12/13-8-44	23.7	24.5
Dortmund	23/24-5-43	35.2	16.3	Bremen	18/19-8-44	108.1	95.6
Barmen	29/30-5-43	84.3	46.6	Russelsheim	25/26-8-44	139.0	89.4
Dusseldorf	11/12-6-43	145.5	72.0	Frankfurt	12/13-9-44	328.2	212.0
Krefeld	21/22-6-43	86.8	44.6	Saarbrucken	5/6-10-44	89.8	54.0
Cologne	3/4-7-43	72.5	40.5	Dortmund	6/7-10-44	305.7	184.3
Mannheim	16/17-4-43	7.5	22.6	Bochum	9/10-10-44	46.1	31.7
Hamburg	24/25-7-43	47.8	20.2	Wilhelmshaven	15/16-10-44	349.8	163.8
"	27/28-7-43	7.7	3.3	Bochum	4/5-10-44	658.4	198.3
Nurnberg	27/28-8-43	3.8	2.2	Freiburg	27/28-11-44	287.2	169.3
Mannheim	23/24-9-43	28.6	15.4	Ludwigshaven	2/3-1-45	182.6	149.5
Hannover	27/28-9-43	3.2	1.4	Magdeburg	16/17-1-45	238.3	223.5
Kassel	3/4-10-43	39.0	25.1	Nurnberg	2/3-1-45	182.7	87.7
Hannover	8/9-10-43	108.9	64.8	Emden	6/9/44)*	463.6	797.5
Kassel	22/23-10-43	216.1	128.8	Munster	12/9/44)*	110.5	315.7
	AVERAGE	57.1	33.4		AVERAGE	218.9	173.5
					Increase over 1943:	3.8 fold	5.2 fold

* Day raids.

It should be explained that low values in the table are due mainly to bad centring of the raid, and much higher densities were achieved away from the aiming point. Thus, in the Hannover raid of 27/28 September 1943 when the rate at the aiming point was only 3.2 tons per square mile, a rate of 120 tons per square mile was achieved at the M.P.I. which was offset nearly four miles from the aiming point. It is a feature of the 1943 raids analysed that the Oboe relative densities are less variable than those of H2S raids; this is due to the more accurate centring of Oboe as a radar device. Most of the H2S raids were at least planned as Newhaven attacks, but if visibility for the visual markers was poor the raid often became badly centred. Oboe densities were not only less variable but, on the average, higher. Nevertheless, the best attack analysed prior to 1944 was the H2S Newhaven attack on Kassel on 22/23 October; this was one of the most devastated towns in Germany.

Time Analysis factors affecting Accuracy

The seventeen 1943 raids were subjected to the process of time analysis briefly described on page 47, whereby each five-minute period in each raid was accorded full Gaussian analysis, much as if it were a separate raid. The completion and publishing of this work was contingent upon the publishing of an earlier report which fully explained the method and examined the validity of the photographic evidence. This report was issued in the Internal Memoranda series.(1) The time-analysis work itself was never completed, being in competition with what were considered more urgent tasks, but some of the data were later issued as Memorandum No. M.97.(2) The following factors may be considered of some interest as affecting the accuracy story.

Time-concentration

The peak five-minute concentration occurred on the average in the fourth five-minute period and was at the rate of 18.6 aircraft per minute for the eight Oboe raids, 23.1 aircraft per minute for the nine H2S raids, and 21.0 for the whole 17 raids. The corresponding one-minute values (i.e. not averaged over five minutes) were 27.2, 32.3 and 29.8 aircraft per minute, averaged over eight, nine and 17 raids respectively.

'Percentage within three miles' value

In the Oboe raids this started at 80 per cent but fell off evenly to 52 per cent in the sixth period. Thereafter it showed a marked recovery, partly because a few Oboe raids did recover after temporary ground-station failure, and partly because averaging was done by superimposing zero-hours and raids were of varying length (the latter half of each time-chart therefore shows increasing variability and the first half is the more reliable). In the H2S raids the value fell off from a peak value of 68 per cent in the third period to zero in the eleventh.

/Thus

(1) 'The Nature and Use of the Photographic Sample in Night Operations'. Bomber Command O.R.S. Memo. No. M.149.

(2) 'The Estimation from Night Photographs, of the Proportion of Aircraft Attacking the Target, 5 August 1943.' Bomber Command O.R.S. Memo. No. M.97. (A.H.B./IIH/241/22/3).

Thus, on the average, raids started well but quickly deteriorated.

Five-Minute Centroid distance from Aiming Point

This measured deterioration in a different unit, by taking the distance from each five-minute M.P.I. to the briefed aiming point and averaging for that period over raids: it was a five-minute systematic error. Its value was minimal at 0.8 miles for Oboe and 1.5 miles for H2S raids in the first period deteriorating to 2.6 miles in the eighth period for Oboe raids and 5.2 miles in the eleventh period for H2S raids.

Area of Five-minute 50 per cent circle

This, which measured dispersion about the five-minute M.P.I. without reference to the systematic error, was optimal at $4\frac{3}{4}$ square miles in the second period for Oboe and at $6\frac{1}{4}$ square miles in the third period for H2S raids. The worst values were $10\frac{3}{4}$ square miles in the sixth period for Oboe and $14\frac{1}{2}$ square miles in the eighth period for H2S raids. Thus raids not only drifted away from the briefed aiming point but also become more scattered.

The evidence of the last three paragraphs suggests that it was the earlier part of the raid which was valuable; the latter half (more or less, in individual cases) was much less effective. The remedy was to dispense altogether with the latter half by making raids shorter, or to concentrate the whole effort into the first 20 minutes or less. It was a fortunate circumstance that evidence on the losses and aircraft damage side also favoured more concentration in time, and the raids of 1944 became much shorter. Concentration in time was followed by concentration in space, since on most raids the five-minute M.P.I. ceased to drift. Raids, as wholes, became better centred and were more nearly circular in shape. The whole trend is forcibly illustrated by the relative aiming-point densities of Table No. 1.

By March 1944 the long series of precision attacks on tactical targets had fully started with the marshalling yard campaign. This inaugurated an altogether new level of accuracy, with relative aiming-point densities averaging nearly 2,000 tons per square mile per 1,000 tons dropped. Investigations into these by O.R.S. will be described below.

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During December 1943 and January 1944 a number of attacks were made by Bomber Command on Crossbow (Flying Bomb) targets in Northern France. In some of these operations heavy bombers, either Lancasters of No. 617 Squadron using the Stablised Automatic Bombsight Mk.IIa or Stirlings of No. 3 Group using the Mark XIV Bombsight, were used, the bombs being aimed at markers dropped by Oboe. The accuracy achieved in these operations was studied using crater plots and marker plots as the sources of data and the results issued as Bomber Command O.R.S. Reports Nos. S.116,(1) S.117,(2) S.123,(3) S.127.(4) The first of these deal with attacks of heavy aircraft and the other two with Oboe bombing raids. These latter, which were purely concerned with the accuracy of Oboe as a device, are discussed in Chapter 13. The general conclusions arrived at from these analyses were:-

(a) The accuracy of bombing with the Stabilised Automatic Bombsight Mk.IIa was about equal to that achieved in practice and in trials. Average radial errors about the marker in the two attacks were 80 yards and 120 yards, the bombing height in both cases being from approximately 13,000 feet.

(b) The bombing accuracy of the crews using the Mark XIV bombsight was considerably less than that attained in practice and this again was less than that of which the sight was capable, as shown in trials. An average radial error about the markers of about 500 yards was the result obtained from a height of about 13,000 feet.

(c) Owing chiefly to errors in range, almost all of them undershoots, the marking accuracy was insufficient, with the bombing accuracy achieved, to produce a good concentration of bombs on the target.

At the same time as these investigations were being undertaken Bomber Command O.R.S. and the Air Warfare Analysis Section were collaborating in studying the results of the attacks on gun batteries in the Boulogne area with particular reference to the accuracy of the attacks, and a joint report, Bomber Command O.R.S. No. S.126 (5) and Air Warfare Analysis Section Report No. 52 was produced. The main sources of data used for the Bomber Command attacks were crater plots of target indicator markers. The craters to be attributed to the attacks of other forces which attacked in daylight were distinguished from those due to Bomber Command attacks by the use of strike photographs. It was found in this case also that the average radial error of bombing on the markers was approximately 500 yards but the inaccuracy of the markers, even those dropped in salvo, was spread out over a distance of about one mile in track.

/The

(1) 'Attacks on Special Military Targets by Aircraft of Bomber Command between 16 and 23 December 1943.' Bomber Command O.R.S. Report No. S.116. (A.H.B./IIM/a1/4a, App. O.R.S.).

(2) 'Attack on Special Military Target at Flixecourt/Domart en Ponthieu by Lancaster of No. 617 Squadron, 30/31 December 1943.' Bomber Command O.R.S. Report No. S.117. (A.H.B./IIM/a1/4a, App. O.R.S.).

(3) 'Oboe Attacks on a Special Military Construction between 29 December 1943 and 5 January 1944.' Bomber Command O.R.S. Report No. S.123. (A.H.B./IIH/241/22/14).

(4) 'Attacks by Mosquitos of No. 8 Group Bomber Command on a Special Target at Herbouville (St. Valery en Caux), 27/28 and 28/29 January 1944.' Bomber Command O.R.S. Report No. S.127. (A.H.B./IIM/a1/4a App. O.R.S.)

(5) 'Statistical Analysis of Attacks on Gun Positions in the Boulogne Area, 8 and 9 September 1943.' Bomber Command O.R.S. Report No. S.126. (A.H.B./IIM/a1/4a App. O.R.S.).

Attacks on Enemy-Occupied Territory 1943 to 1945

Night Precision Attacks in 1943

In the second half of 1943 a number of attacks were made on factories and similar targets, mainly in France. These attacks were carried out in the moon period against ~~any~~ only light defences and it was considered by the Command that a high degree of accuracy would be achieved and that heavy damage to these precision targets would thereby be accomplished. Crater plots were obtained for three of these attacks and analysed.[1] ~~the results being presented in Bomber Command O.R.S. Report No. S.109.(1)~~ These three attacks were carried out using different techniques and it was therefore possible to use the results of this analysis to evaluate the comparative merits of the techniques as well as to detect the defects common to them all. Two of the attacks analysed employed ground-marking techniques and in the remaining one the target was illuminated by flares throughout the attack and the bombing was visual. A number of useful conclusions were reached and recommendations made among which were included:-

> (a) When visual bombing was relied on, the target area was rapidly blanketed by smoke and could not be seen. On the other hand the point of aim could be adequately indicated by ground markers.
>
> (b) The average random error of bombing was 400 to 600 yards from 5,000 to 14,000 feet. This was well below the capabilities of the sight.
>
> (c) Marking accuracy was not sufficient to ensure that the main concentration of bombing fell on the target and needed to be considerably improved if the accuracy of the main force was to be taken full advantage of. Increased attention to bombing accuracy by all crews, and particularly by marker aircraft, was therefore required.
>
> (d) An appreciable systematic error in the bombing of the markers could occur and in the case of an attack by No. 4 Group this was apparently due to aiming the first bomb of the stick thereby causing an overshoot.

When this report was issued it was established that No. 4 Group had in fact been aiming the first bomb and not the stick centre. A method of introducing the appropriate correction by oversetting target height was sent to the O.R.S. representative at the group so that he could make the necessary calculations until the Royal Aircraft Establishment computer, which was being developed, became available. In March 1944, however, a more exact formula for calculating this correction was provided by M.A.P. and passed to the Armament Branch of the Command, it being intended that they should calculate tables and issue them as a Bomber Command Armament Staff Instruction. At the same time this formula was transmitted to the O.R.S. representatives at groups. The calculations were, in fact, performed by O.R.S. at the beginning of May 1944, when an electric calculating machine became available, and were then issued by the Command's Armament Branch as Bomber Command Armament Staff Instruction, Part I, Section J. Leaflet No. 1.

/During

(1) 'Bombing Accuracy at Night - Precision Targets.' Bomber Command O.R.S. Report No. S.109. (A.H.B./II H/241/22/14).

The results of these investigations into the accuracy of operations against precision targets started two lines of attack on the shortcomings revealed. The difference between operational results and practice results with the Mark XIV bombsight, and the further difference between practice results and the potentialities of the sight, caused the O.R.S. to institute enquiries into the reasons for the discrepancy. These enquiries included an examination of the state of training in bomb-aiming and initiated the work on practice bombing described in Chapter 10. In addition data on the winds set on the bombsight was obtained in order to discover whether there was sufficient variation in these to account for the increased dispersion of the bombs. It was found that in the attacks on Crossbow targets the vector errors were distributed normally about the mean wind used with an average vector error of about 10 m.p.h.; the average values for individual raids varied between 6 m.p.h. and 17 m.p.h. A vector error of 10 m.p.h. is equivalent to approximately 150 yards on the ground when bombing with H.E. bombs from the heights flown in these attacks. Thus the entire removal of this cause of dispersion would only have reduced the average radial error of bombing from 500 yards to about 475 yards and it was clear that this factor was not of any very considerable importance.

In addition to investigations designed to decrease the dispersion of bombs about the markers, investigations were also directed towards improving the accuracy of marking. These were partly concerned with the accuracy of the Oboe system, and this aspect is covered in Chapter 14. In addition the ballistic characteristics of target indicator markers and the problems of aiming airburst cluster projectiles were studied. There were also doubts of the stability and ballistic consistency of target indicators and bombs when released from the heights and at the speeds used on Oboe operations and these points also were investigated.

Attacks in Support of the Campaign in Northern France and Belgium, 1944.

As far as Bomber Command was concerned the tactical campaign which prepared the way for and assisted the landings in Normany and the subsequent land operations began with a series of operations against marshalling yards in France and Belgium and continued throughout the summer with attacks on coastal batteries, road choke points, ammunition depots, troop and mechanical transport concentrations and airfields. In June, July and early August also a very considerable amount of the Command's effort was expended against the launching points and storage sites for flying bombs. Throughout the whole of this period a close watch on the

/accuracy

accuracy of bombing that was being achieved was necessary in order to ensure that, in view of its manifold tasks, the force at the Command's disposal was used to the fullest advantage. This series of attacks opened with the attack on Trappes Marshalling Yard on the night of 6/7 March 1944 and from that date O.R.S. was busily occupied for several months almost entirely in quantitative analysis of these attacks in order to provide the Air Staff of Headquarters Bomber Command with detailed information of the results being achieved and with suggestions for improvement.

The Attacks on French and Belgian Marshalling Yards March to April, 1944.

The work done on the accuracy of this series of attacks was of two types. An immediate examination of each attack designed to elucidate its structure and to determine the extent to which it had succeeded in its object was undertaken and also a detailed analysis of the crater plots was carried out which enabled a comprehensive review of the bombing accuracy achieved in this campaign to be made. The immediate examinations were published as the series of reports and summaries described on page 38. In these reports there was included a comparison between the results achieved expressed both as hits per acre of the target area and as percentage of bombs despatched falling on the target and the expectation based on the accuracy assumed in planning this series of operations. These comparisons gave an overall measure of the accuracy which was being achieved but, without the more detailed analysis which required more time, the causes of differences could not be fully elucidated.

In these reports and summaries the actual achievement was measured by direct counts of the craters visible on plots made by 'K' Section of the Allied Central Interpretation Unit and, as was pointed out on page 33 this leads to an underestimate of the result due to a proportion of the craters being missed. However, in Bomber Command O.R.S. Report No. S.159,[1] in which the results of the first 15 attacks are discussed, this fact is considered and allowance made for these missed craters. When this was done it was found that the results achieved were only 72 per cent of those expected. The reasons for this discrepancy only became apparent, however, as a result of the detailed analysis of crater plots.

This detailed analysis is fully described both as to the methods employed and the results obtained, in Bomber Command O.R.S. Report No. 167 [2]. It is desirable, however, to summarise the findings here as a preliminary to recording the subsequent action. There were:-

(a) The proportion of gross errors was 27 per cent, this large figure being mainly due to gross marking errors which attracted bombs away from the main clusters.

/(ii)

(1) 'Summary of 15 Oboe Groundmarking Attacks on Marshalling Yards, 6/7 March to 10/11 April 1944.' Bomber Command O.R.S. Report No. S.159. (A.H.B./IIH/241/22/14).
(2) A.H.B./II/39/1/1.

(b) The average overall systematic error was 485 yards. The average error of the markers was 330 yards which was of the expected order but the M.P.I. of the bombing was appreciably displaced from the markers, its average distance being 350 yards from them. This displacement showed a starboard bias of 200 yards but greater variation in range than in line. Flat turns were suggested as the possible cause of the starboard bias and incorrect target pressure settings and fake height settings to correct for stick length to account for the spread in range.

(c) The radial standard deviation of the bombs about the M.P.I. averaged 540 yards. Even after correcting for the increased dispersion in range due to the bombs being dropped in sticks it was found that the random errors in range were slightly larger than those in line. This spread was considerably greater than current practice results and although the gap was narrowed when allowance was made for the spread of markers within the groups aimed at and also the variation in winds used, it was still considerable.

This report was drafted by 16 May 1944, but, for a variety of reasons, was not issued until more than two months later. The results of the analysis were, however, available to the Armament and Training Branches of the Command and also to M.A.P. even before the draft was completed and much was done to bring about improvements. The drive on marking accuracy using Oboe which was stimulated by the reports on the individual attacks is described in Chapter 14 and in Chapter 3 the improved marking technique with the use of a Master-Bomber is discussed. The recommendation that Automatic Observers should be installed in some aircraft of the main force in order to check the quality of the flying during the bombing run was passed to the Armament Branch on 7 May and implemented by them.

Another result of this analysis was an informal meeting on bombing accuracy problems held at M.A.P. on 5 May 1944, under the chairmanship of Research & Development Instruments 2. It was at this meeting that the suggestion was made that the variation in range of the M.P.I. of the bombs relative to that of the markers ~~was made and it was agreed that this point~~ should be investigated. This meeting was also of the opinion that increased training and practice in bomb-aiming were required and that the analysis of bombing practices should be more carefully controlled so that the causes of errors would be detected. This opinion was by no means confined to those present at the meeting, but was shared by all who were concerned with the problem. It resulted, amongst other things, in the setting up of the Bomber Command Analysis School on the initiative of the Command's Training Branch and in the general drive on bombing accuracy and bomb-sight maintenance.

It was this general drive on bombing accuracy which was without doubt the most fruitful of the various measures taken at this stage. More frequent practices, better maintenance and, above all, the engendering in the aircrews of an enthusiasm to attain the maximum possible accuracy on

/operations,

operations, produced great and rapid improvement which was stimulated by a healthy amount of inter-group rivalry. Knowledge of the difference between what was being achieved and what might be was the basis of this propaganda and since that knowledge was provided by the analysis carried out by O.R.S. they can claim a considerable share of the credit for the improvement which took place.

Attacks on Tactical Targets, May to September 1944

The extent of this improvement was revealed by the further analyses of crater plots on various targets in France attacked during the summer. The results of these were issued as a series of reports on the accuracy of groups within the Command and summarised in Bomber Command O.R.S. No. S.184.(1) In these reports it was shown that the overall systematic error was reduced on the average to about 300 yards and the starboard bias was eliminated. The random error was also reduced so that the radial standard deviation about the M.P.I. became on the average approximately 440 yards. The reduction in the overall systematic error was due not only to improved marking accuracy and a smaller systematic error in bombing the markers but also to the influence of the Master Bomber, when there was one, in counteracting to some extent the errors in marking.

From these later investigations, which showed that so satisfactory an improvement had taken place, further steps to produce improvements did not, as in the earlier case, ensue. Their value was principally in providing definite information on what the Command was likely to achieve thereby enabling the operations of the Command to be planned with some precision. This was of particular value in delineating a bomb-line in attacks carried out in close support of the ground forces. An account of the work in this and similar directions will be found in Chapter 6 .

In addition to the detailed analyses of crater plots, which could only be carried out for a comparatively limited sample of raids, counts of the craters within a 20-acre circle centred at the aiming point were made for some 200 raids during this period. The results were expressed as bombs per acre per 1000 dropped, a measure referred to as the relative density. Two detailed reports based on statistical analyses of these relative densities were prepared, one covering night attacks in the period March to June 1944 and the other covering day attacks from June to September 1944. These reports were not published at the time but a summary of the two was issued as Bomber Command O.R.S. Report No. S.192.(2) The two full length reports were, however, later included in the series of Internal Memoranda. These reports were concerned principally with comparison of the various techniques of attack employed, but they also considered the effect of the height of attack, the weather, and the defences on the accuracy of bombing and compared the accuracy of the difference groups. The reports on the day attacks, Nos. S.182 (3) and 183, (4) made

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(1) 'Daylight Operations in Bomber Command for Six Months ending 30 June 1942.' Bomber Command O.R.S. Report No. 52. (A.H.B./II/39/1).
(2) 'A Preliminary Note on Bombing Accuracy in Daytime.' Bomber Command O.R.S. Report No. 41. (A.H.B./IIK/46/46B).

strong recommendations in favour of formation Oboe and No. 5 Group visual marking techniques and a comment may perhaps be permitted on this point. No mention is made in the report of the fact that if further operations were confined to these techniques almost 75 per cent of the Command's operational force of heavy bombers could not have been used. The weight of attacks made by formation Oboe was also very severely limited. If the findings of this report were to lead to any improvement they needed to contain some suggestion of the ways in which it might be possible to make the results of attacks in which the main and marker forces were drawn from groups, other than No. 5, approached more closely those obtained by that group.

The Attacks on Coastal Batteries, May to June 1944.

The investigations discussed in the last three paragraphs dealt with the whole of the Command's effort against small targets in France and the Low Countries. These were supplemented by an examination of the attacks on coastal batteries which were carried out in the month preceding the landing in Normandy. This examination, which was undertaken in order to provide the Air Staff of Bomber Command with information necessary for the planning of the attacks on the night of the landing, was based on counts of craters within a 20 acre circle about the aiming point and reports, provided by the Allied Central Interpretation Unit, of the damage sustained by the guns. As a result of this examination the use of Oboe ground marking on that night was considered to be desirable since it was less susceptible of being disturbed by adverse weather conditions. With the use of this technique an effort of 100 sorties was deemed sufficient for an adequate expectation of doing the requisite amount of damage to a battery. The memoranda prepared at this stage for the Air Staff were included in the series of Internal Memoranda as Bomber Command O.R.S. Nos. M.105(1) and M.106.(2) In spite of thin cloud on the night of 5/6 June the attacks succeeded sufficiently to ensure that artillery opposition to the landings was not serious.

A review of these attacks was issued by the R.A.F. Bombing Analysis Unit after that unit had commenced ground survey work in France as B.A.U. Report No. 10.(3) This report, which was intended to serve as a background for the accounts of the ground survey of individual batteries, was based on photographic reconnaissance data. Since this report was in many respects at variance with the conclusions of O.R.S. Bomber Command on this series of attacks a report, Bomber Command O.R.S. Report No. S.207(4) was prepared in which the O.R.S.'s views were set out. Following discussion with the Bombing Analysis Unit the greater part of the differences were resolved and both parties agreed on an appendix to the staff study on the 'Fire Support of Seaborne Landings' prepared by the Joint Technical Warfare Committee.(5)

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(1) 'Note on the Attack of Coastal Defence Guns, 27 May 1944.' Bomber Command O.R.S. Memo. No. M.105. (A.H.B./II/241/22/3).
(2) 'A Preliminary Analysis of Attacks on Gun Batteries, 30 May 1944.' Bomber Command O.R.S. Memo. No. M.106. (A.H.B./II/241/22/3).
(3) R.A.F. Bombing Analysis Unit Report No. 10. (A.H.B./IIS/136/1-10).
(4) 'Attacks on Coastal Defence Batteries by Bomber Command.' Bomber Command O.R.S. Report No. S.207. (A.H.B./IIH/241/22/14).
(5) A.H.B./ID5/56/5.

It was also agreed in the course of these discussions that the Bombing Analysis Unit would issue an amended and corrected version of its Report No. 10.

Operations with the Stabilised Automatic Bombsight Mark IIa

The operations carried out by No. 617 Squadron, using the Stabilised Automatic Bombsight Mark IIa, were studied at the same time as those of the ordinary squadrons of the Command using the Mark XIV sight and the results were presented in Bomber Command O.R.S. Report No. S.184.(1) This report did nothing more than give figures for the accuracy achieved and made no recommendations.

Towards the end of 1944 No. 9 Squadron, using the Mark XIV bombsight, began like No. 617 Squadron to carry out squadron precision attacks on special targets using the Tallboy bomb. The results achieved by these two squadrons thus provided a comparison of the possible accuracy of the two bombsights under similar very favourable operational conditions and such a comparison is made in Bomber Command O.R.S. Report No. S.226.(2)

In February 1945 No. 617 Squadron came to the conclusion that they were getting a consistent overshoot on operations and therefore proceeded to put a false setting on the sight in order to correct for this. When Bomber Command O.R.S. Report No. S.226 was issued it stated that the results of their analyses confirmed the existence of the overshoot and justified the false setting. Research and Development (Instruments 7 and Armaments 14) of the Ministry of Aircraft Production, however, demonstrated by an analysis of variance that this conclusion could not be arrived at on the basis of the available evidence and that the statistical procedure used by O.R.S. was faulty. They showed that, in range but not in line, the variance of the means of attacks, i.e. the between raids variance, was significantly greater than that within raids. It was therefore inappropriate to consider the distribution about the aiming point of the bombs from different attacks as a single one and to test the significance of the separation of the compound M.P.I. from the aiming point on that basis. It was thus clear that there was some factor causing substantial errors in range which was constant for a particular raid, but there was no evidence that there was any constant bias in its operation. An amendment to Bomber Command O.R.S. Report No. S.226 was therefore issued.

Attacks on Germany 1944 to 1945

The work done by O.R.S. Bomber Command on bombing accuracy after the conclusion of the summer campaigns of 1944, and when almost all targets came once more to be located in Germany, carried on the methods previously used and does not call for any extended treatment. In December 1944

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(1) 'Bombing Accuracy in Bomber Command against Lightly Defended Targets.' Bomber Command O.R.S. Report No. S.184. (A.H.B./IIH/241/22/14).

(2) 'Bombing Accuracy on Operations, Nos. 9 and 617 Squadrons' Bomber Command O.R.S. Report No. S.226. (A.H.B./IIH/241/22/14).

Bomber Command O.R.S. Report No. S.197 [(1)] was issued. This was based on six crater plots, five of raids which employed the Newhaven marking technique (see page 68) and one Oboe ground marking. This report showed that the errors were considerably greater than in the attacks on lightly defended targets in France and the Low Countries, but nevertheless they showed a very great improvement over the results of 1943.

Bomber Command O.R.S. Report No. S.209 [(2)] covered a series of 16 day attacks carried out during the period September to December 1944. The information was based, for some attacks, on crater plots and, for others, on plots of the distribution of bomb-fall made by plotting forward from the photograph taken at the moment of bomb release. The attacks discussed in this report were all comparatively shallow penetrations and the marking was, in most cases, done by Oboe. A number of interesting conclusions were drawn in this report, the most interesting, probably, being that whilst the intensity of flak opposition affected the proportion of gross errors it had no effect on the accuracy with which those bombs which are not gross errors were dropped. It was also shown that the systematic errors were no larger than those which had occurred in comparative attacks on France and the Low Countries, but that there was an increase in the random errors about the M.P.I. greater than could be accounted for by the increased height of attack. In addition there was a significant tendency for the M.P.I. of the bombing to lie to starboard rather than to port, its average position in line being about 200 yards to starboard. This starboard bias occurred in the attacks carried out in March and April 1944 on French and Belgian marshalling yards, but had disappeared when other errors had been reduced.

These two reports did not lead to any improvement, but they, along with the less precise figures derived from plots of night photographs, did provide the information on which to base calculations of force requirements and probabilities of success which were in considerable demand at this time (see Chapter 5). The average figures for the proportion of gross errors, the systematic error and the random error for each type of attack were kept continuously available for this purpose. These did not usually change much and those in use at a particular date in February were published as Bomber Command Report No. B.232.[(3)]

There was an appreciable lag in the preparation of crater plots, particularly during the early months of 1945, when this work was being done by R.E.8 and was in competition with a number of more urgent tasks which they were required to perform. As a result information concerning a considerable number of attacks came to hand after the conclusion of hostilities, when there was no longer the same urgency for making results available. The opportunity of combining the publication of this additional /data

(1) 'Bombfall Distribution in Night Area Attacks on German Cities.' Bomber Command O.R.S. Report No. S.197. (A.H.B./II/35/1/1).
(2) 'Bombfall Distribution in Day Attacks on Targets in Germany.' Bomber Command O.R.S. Report No. S.209. (A.H.B./IIH/241/22/14).
(3) 'Present Parameters of Bomber Command Attacks.' Bomber Command O.R.S. Report No. B.232. (A.H.B./IIH/241/22/12).

data with a comprehensive review of the information obtained from crater plots was therefore taken and Bomber Command O.R.S. Report No. S.237 (1) was issued. This included a tabulation of the average figures for the various error parameters for each technique of bombing.

In this report the effect of height on bombing accuracy was considered. It was found that the range of heights of the attacks on German targets was too limited for such an investigation and it was therefore necessarily confined to the results of the attacks on France and the Low Countries. From these attacks three series of about ten each were available, each series consisting of comparable attacks in that the marking technique and general conditions of attack were the same. There were, however, appreciable differences between the accuracies of the different series. The correlation of each of the three error parameters, proportion of gross errors, systematic error and random error with height was then examined for each series. For gross errors and systematic errors it was found to be negligible in all cases but there was considerable positive correlation between random errors, expressed as the radial standard deviation about the M.P.I., and height for each series. Since this was of the same order in all three cases it was considered reasonable to combine all three series and obtain thereby a sample large enough to give more precise information on the nature of the relationship. In order to obtain comparable figures for this purpose, the radial standard error for each individual attack was divided by the average value for the series of attacks to which it belonged. A highly significant correlation between the resulting ratios and the height of attack was found.

The height error relationship in bombing has normally been considered to be a power law of the type:-

$$\text{Error} = a\,h^{x}$$

where a is a constant, h is the height and x has a value less than 1. In order to obtain a value for x the logarithms of the height and the random error ratio were obtained and the regression co-efficient of the latter on the former was determined. This, which was 0.24, is the required figure. The value so obtained can, however, only be regarded as a first approximation since the average heights of attack for the different series of raids differed. The average value of the radial standard error for each series of attacks was therefore corrected to 10,000 feet from the average height for that series using the relationship that error was proportional to the fourth root of the height. The calculations were then repeated and the value of the regression co-efficient obtained then became 0.27. This figure which had a standard error of 0.066 was the best that could be deduced from the data available. Whilst appreciably less than the figure

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(1) H2S Blind Bombing Illuminating and Marking Accuracy, October 1944 to April 1945 (German Cities excluding Berlin). Bomber Command O.R.S. Report No. S.237. (A.H.B./IIH/241/22/14).

of 0.36 derived from practice bombing results it was not significantly different from it.

The other subject discussed in this report is that of the systematic starboard bias of about 200 yards, which was found to have occurred in more than one series of attacks. It was pointed out that it occurred when the random errors of bombing were greater than the best obtainable and it was suggested that the principal factor concerned was the standard of flying during the bombing run. If this were the case, it would indicate that when the pilot's attention to detail in the technique of his flying was somewhat relaxed, yaws to port occurred with much greater frequency than yaws to starboard.

A further investigation, published as a Bomber Command O.R.S. Report, [illegible] that was not completed until after the conclusion of hostilities, was one into the distribution of systematic errors with different marking techniques and in different conditions. This investigation had two aims, to ascertain the comparative merits of the various marking techniques in indicating the correct point of aim, and to discover whether there was justification for the assumption made in force requirement calculations that the M.P.Is of bombfall in a series of attacks using the same technique and in the same conditions would be distributed about the aiming point in accordance with the normal radial probability law. All available data from crater plots, plots of night photographs and plots made from photographs taken at bomb release for a period of 12 months was used. The detailed comparison of the various techniques will be found in the report. For the investigation of the normality of the distribution it was necessary to make use of all the information together, owing to the comparatively small number of attacks carried out by the same technique and in comparable conditions. This was done by calculating the radial standard deviation of each comparable group of M.P.Is. about the aiming point and dividing the individual values by this figure. The radial error of each M.P.I. was thus expressed as what might be termed a normal radial deviate. The numbers of these in successive annuli were compared with the expected number as given by the formula for the normal radial distribution and the significance of the difference examined by a chi-squared test. The result of this test was to show that there was no significant departure from normality and the assumption of normality therefore appeared justified.

In the winter of 1944/45 a considerable proportion of Bomber Command's effort was expended in attacks carried out through 10/10ths cloud and it was therefore desirable to try and obtain a comparative measure of the accuracy achieved in such conditions and in clear weather. An attempt to do this was made using the estimates of tons of bombs falling per kilometre square prepared from studies of the amount of damage made by R.E.8. As a preliminary to this the distribution of attack so deduced

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was compared with the distribution of night photographs in the case of a small number of attacks carried out in clear weather. The discrepancies were so large that it was clear that further investigation into the reliability of the data was required. No conclusion appear to have been reached, and therefore recourse made to the limited number of crater plots for such raids and a report, Bomber Command O.R.S. Report No. S. 237[1], based on these, was prepared in which it was shown that such raids were appreciably less accurate than those carried out in clear weather, particularly as regards systematic errors.

Attacks carried out by bombing in formation were studied separately by O.R.S.5 who were concerned with the accuracy of radar devices. These were reported on in Bomber Command O.R.S. Report No. S.211[2] which is discussed in Chapter 3.

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(1) "H2S Blind Bombing Illuminating and Marking Accuracy October 1944 to April 1945 (German Cities Excluding Berlin)". Bomber Command O.R.S. Report No. S.237. (A.H.B./II/39/1/1).

(2) "An Analysis of Gee-H Raids (October to December 1944)". Bomber Command O.R.S. Report No. S.211. (A.H.B./II/39/1/1).

CHAPTER 6
PLANNING OF OPERATIONS

Introduction

A knowledge of weapon effectiveness and of bombing efficiency and accuracy within Bomber Command have many applications in furthering the effectiveness of operations but one of its most important applications lies in assessing the weapon and force requirements for a given task. Such an assessment can prevent either the waste of effort and bombs through overhitting or attempts to neutralize a target with an inadequate force, a matter which becomes very important when the time factor is of prime interest. It was essential also in appreciating a strategic or tactical plan of bombardment requiring the neutralization of a set of targets in a given time in order to assess whether the task was within the powers of the force available.

Assessments of this nature require an acquaintance with the laws of probability as well as in intimate knowledge of bomb performance and bombing efficiency, and, in the case where a series of targets were involved the assessor had to be aware not only of the influence of such things as weather conditions in bombing efficiency but also the frequency with which various sets of such conditions are likely to occur. For these reasons it was natural that the responsibility for planning calculations of this nature should fall upon the O.R.S. Nor was their work in this field confined to the requirements of the Command for from time to time they were called upon to advise the Air Ministry in those matters.

Planning of Special Operations, 1942 to 1943

Until the end of 1943 the question had arisen only infrequently because at that time the Command seldom attacked targets other than German or Italian towns and the strength and efficiency of the Command at that time rendered it unlikely that such targets would be overhit even when the whole force was used. From time to time however such problems did arise. It is impossible to chronicle all of them because they eventually became too numerous and, particularly in the early days, they were of such a confidential nature that records were seldom kept in the usual way.

As far as can be recalled the first estimate of this nature was made in August 1942 when the target postulated consisted of a row of pylons at a radio station. The operation was not, in fact, carried out. Early in 1943 came the first discussion in calculating weapon and force requirements when the possibility of using the heavy bomber force in support of land and sea operations was first mooted. This was in connection with Operation Constellation which involved a sea-borne landing on one of the Channel Islands (Alderney) as a diversion to similar operations in the Mediterranean.

The task of the heavy bombers was to neutralize coastal defence guns and beach defences such as machine gun posts, wire, minefields and anti-tank obstacles. The problem was to choose the most effective bombs,

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decide what densities were required in the various areas of the target, and work out the force required and the best disposal of aiming point to achieve these densities. The purpose was not only to assist in the planning of such an operation but even more to assess whether the task was within the capabilities of the bomber forces available. During the same period proposals discussed at Air Ministry regarding possible new directives gave rise to appraisals of the railway system in enemy and enemy-occupied territories and of synthetic oil plants in the Ruhr.(1)

The method used in all these problems was basically the same throughout. The layout of the target complex and the construction of the subtargets was examined as carefully as available data would allow. Experimental data or the results of operational analysis on the effect of bombs were then studied so that a radius of effectiveness or mean area of effectiveness could be postulated if not already directly available for the range of bombs likely to be useful. Where necessary the advice of relevant experts, such as those in the Research and Experiments Department (R.E.8) of the Ministry of Home Security, was sought. From these figures the best type of bomb-load and the number of hits on the target or the density required over the target area could be derived. Such information as existed on the efficiency of the Command was then manipulated so as to give the number of aircraft which must be dispatched to give a prescribed chance of achieving this density. This would of course take into account such things as weather, range of target and the nature of the defences likely to be encountered. If a series of attacks were involved it could then be stated how many sorties in all were required to produce a given expectation of successful attacks.

The statistical methods involved were straightforward; sometimes ad hoc calculations were made, sometimes probability grids were used. In the earlier days however, difficulty arose in the scarcity of quantitative information both on the weapon effectiveness and the bombing efficiency aspects, and it was necessary to make bold estimates of the parameters involved. As time went on, however, this difficulty was gradually resolved and the estimate became more and more reliable. This was fortunate for at the same time the necessity for such estimates and their importance increased as the possibility of the use of heavy bombers in the tactical scheme became more real.

A second plan similar to Operation Constellation but this time based upon targets on the coast of France between Boulogne and Calais (Operation Starkey) was studied and then, in September 1943, the whole subject of fire support for an opposed landing was reviewed by an Inter-Service Committee. O.R.S. Bomber Command was called in to make an appraisal of the part which could be played by heavy bombers and the force likely to be required and this was included in the Committee's report.(2)

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(1) See A.H.B. Narrative 'The Liberation of North-west Europe', Vol.1. Chap.7.
(2) A.H.B./IIS/136.

Planning of Operations in 1944

The railway system question arose again in January 1944 and became urgent a few weeks later when a proposal was made to use the heavy bombers both of the R.A.F. and U.S.A.A.F. in an attempt to cripple the transport systems, first of France and Belgium and later of Germany, as a preliminary to landings on the Continent.(1) Estimates made by A.E.A.F. of the effort required were considered to be grossly optimistic and independent estimates were offered to the Air Staff and were finally adopted by Air Ministry. This involved an examination of a large number of marshalling yard targets in consultation with railway experts to determine the density of bombs to be aimed at and the best disposition of aiming points. Probability grids based on the latest accuracy parameters were made in order to facilitate the problems of obtaining the expectation of hits on a large number of irregularly shaped targets and the results were used not only to appraise the total tonnage requirements for the plan but also, when the operation started, to calculate the force requirements for each operation separately. The results of the attacks were carefully studied and compared with the forecast which was found to be reasonably accurate.

This was followed by a similar appraisal of a series of airfield targets which were part of the same pre-assault plan and then of ammunition dumps and, finally, the coastal batteries of the cover plan. Indeed from the beginning of 1944 until D-day operational planning work of this nature became a constant feature of the O.R.S.'s activities. Nor was there much respite after the landing for as soon as the troops were held up in Normandy the problem of close support arose with targets such as troops or tank concentrations, the destruction of villages to block vital roads and defence positions of all kinds. It was evident with many of these latter targets that the inflicting of a high degree of physical damage on the small dispersed sub-targets would involve prohibitive effort and great importance was therefore placed on positioning our troops as near to the target as possible so that full advantage could be taken of the 'stunning' effect which was known to last for only a short time. The dangers of being too near are obvious and in order to find the best compromise, bombfall patterns were carefully studied and a 'bomb line' representing the smallest safe distance to the aiming point to which our troops could approach was produced.

Concurrently with the planning for Operation Overlord the question of combatting the V-weapon offensive by knocking out launching sites, interfering with transport and attacking factories and store places was considered. These targets came on to the Bomber Command programme at the end of 1943 and as they later assumed greater importance typical targets were reviewed from the weapon effectiveness and force requirement aspect in order to ensure the most efficient use of the force available. The

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(1) A.H.B. Narrative 'The R.A.F. in the Bombing Offensive against Germany,' Vol.VI Chap.1.

matter received more and more attention as the menace grew and, finally, in July 1944 the whole question was referred to the Combined Operations Planning Committee. A member of Bomber Command O.R.S. was co-opted onto the committee and with the collaboration of the Operations Analysis Section of the VIIIth Air Force recommendations as to the type of bombs and fusing together with required densities for the various types of targets were made.(1) The effort required in the case of Bomber Command to give a 50 per cent probability of reducing these targets was calculated.

On 18 October 1944 Bomber Command O.R.S. was called at very short notice to a consultation with representatives of the Directorate of Bomber Operations, Air Ministry, R.E.8 and the Operations Analysis Section of the VIIIth Air Force to provide information on the forces required to destroy the bridges over the Rhine between Basle and Emmerich. This information was required for a conference to be held at SHAEF on the following day at which the feasibility and desirability of this project was to be discussed. At this meeting the weapon requirements and numbers of hits required were calculated on the basis of the data as to the capabilities of the bomber forces provided by the two research sections.

The next of these planning tasks which is worthy of mention was in connection with the bombing of submarines under construction. In this case R.E.8 advised that a direct hit or a near miss within 20 feet of a submarine under construction was required if its building was to be substantially delayed. The method of calculating the force requirement adopted in this case was given the expected standard deviation of the bomb pattern, to calculate the number of bombs which it was necessary to drop in order to achieve a 50 per cent and a 75 per cent chance of a hit on a rectangle of area equal to the plan area of the submarine plus the near miss distance assuming that the centre of the rectangle was at the same distance from the centre of the distribution as the most distant submarine was from the centre of the slips, which would, it was assumed, be the aiming point. The figures thus arrived at therefore gave slight over-estimates of the forces required to damage 50 per cent and 75 per cent of the submarines on the slips. The results of this enquiry may be found in Bomber Command Memorandum No. 111.(2)

In November 1944 the O.R.S. were asked to estimate the effort which would be required by Bomber Command to prevent Germany obtaining any oil from the oil plants which were at that time allocated as targets to the bomber forces operating from Great Britain. This involved determining the relationship between the density of bombing achieved and the time the

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(1) A.H.B./IIH/241/22/3 (Bomber Cmd. O.R.S. Int.Mem. No.108).
(2) A.H.B./ID3/1773A.

plant was out of operation and from that obtaining the optimum density of bombfall. This was done by using the results of past operations obtaining data on the accuracy of American attacks from the Operations Analysis Section of the VIIIth Air Force and on the activity of the plants on various dates from R.E.8. From this it proved possible to estimate the optimum density of bombfall, which was one ton per acre, and also to provide estimates which proved reasonably accurate of the length of time which such densities would put the plants out of action.

In all previous calculations of force requirements the systematic and random errors of bombing were compounded and no account was taken of their relative magnitudes. It was in effect assumed that the bombs would fall in a normal probability pattern about the aiming point with a standard deviation equal to the square root of the sum of the squares of the standard deviation of the mean points of impact of a series of raids about the aiming point and the average standard deviation of the bombs in a raid about their M.P.I., and probabilities of hits and expected densities were computed on this basis. Whilst this provides the average results over a number of raids there will clearly be considerable variation from raid to raid. It was decided at this stage that it was necessary to have a more realistic picture of what actually happened in order to take this variation into account. A short note on an approximate method of specifying the probability that the density of bombing at the aiming point would attain or exceed a given figure was accordingly written and the formulae evolved were used for the calculations in hand on forces required for the attack on oil. This note is Bomber Command O.R.S. Memorandum No. M.113.(1)

Whilst the formulae evolved take the systematic and random errors into account separately they are based on two simplifying assumptions which make them only approximate. The first of these is that the distribution of bombs can be treated as if bomb density were a continuous smooth variable decreasing with distance from the centre of the bomb pattern, in accordance with the normal two-dimensional probability equation. If the target is large enough for the expected number of hits on it to be considerable, taking into account the number of bombs to be dropped, and yet small enough in relation to the standard deviation of the pattern for the change of density over it to be small, the approximation will be close. However, if the target and the number of bombs to be dropped is such that the expected number of hits is small the discontinuity of the bombfall distribution must be taken into account. The other simplifying assumption is that the standard deviation of the bombs about their centroid is the same from raid to raid. In practice, however, this

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(1) 'The Probability of Achieving a Given Density of Bombing at the Aiming Point, 2 December 1944.' Bomber Command O.R.S. Memo. No. M.113. (A.H.B./IIH/241/22/3).

varied from raid to raid and the overall effect of such variation was to decrease the probability of achieving a given result with a given quantity of weapons.

This method was elaborated a little further and put forward in some detail with graphs to assist in rapid determination of the required answers in Bomber Command O.R.S. Report No. 124.(1) A further report with more practical detail and containing current figures of Bomber Command accuracy was produced at the instance of the Air Staff as Bomber Command O.R.S. Report No. S.227.(2) The first note was shown to Dr. Bronowski, one of the mathematicians of R.E.8 with whom the writer of the note was in contact at the time on weapon effectiveness matters and, as a result, he worked on the problem of producing more exact formulae and determining the errors caused by the various approximations made. A joint paper resulting from this work was drafted later.

Further work of this type on problems of close support bombing, attacks on the German railway system, and on an underground factory will be found in Bomber Command O.R.S. Report Nos. B.229,(3) B.231(4) and B.234.(5) There were in addition other similar problems tackled which did not give rise to formal reports.

Area Attacks

During 1943 and early 1944 Bomber Command O.R.S. was keeping in touch with the work on weapon effectiveness which was being done, mainly by R.E.8, and advising the Air Staff of the Command on the relative merits of different types of bomb for area attack. At this stage the accuracy attainable was such that the full force of the Command was necessary for each attack and force requirements calculations were therefore not needed. In the winter of 1944/45 when a return to area bombing took place it was clear that the increase in accuracy of the Command was such that serious over-hitting was occurring. The O.R.S. was therefore asked to look into the question of the size of forces required for towns of different areas and also into the question of the desirable distance apart of aiming points when the target was large.

The mathematical problems raised by area bombing are far from simple. The complications are due to the fact that the density of bombing cannot be treated as constant over the whole target area and the amount of damage done is a negative exponential function of the density of bombing. The whole subject is discussed exhaustively in A.W.A.S. Departmental Note No. 11. Bomber Command O.R.S. using equation 13 of that paper, carried out calculations on the tonnages of bombs to be dispatched to destroy 70 per cent of the buildings in a circular target of varying radius and using techniques of different accuracy. This

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(1) 'The Technique of Raid Analysis and Forward Planning.' Bomber Command O.R.S. Report No.124. (A.H.B./II/39/1).

(2) 'Practical Methods used in Forward Planning of Bombing Operations.' Bomber Command O.R.S. Report No. S.227. (A.H.B./IIH/241/22/14).

(3) 'Preliminary Note on Density Achieved in Close-support bombing of Rectangular Area 1000 yards wide.' Bomber Command O.R.S. Report No. B.229.

(4) 'Estimation of Effort required against German Marshalling Yards.' Bomber Command O.R.S. Report No. B.231. (A.H.B./IIH/241/22/12).

(5) 'Estimate of Effort required on Target GN.5062 with a note on the probable Effects of Attack. Bomber Command O.R.S. Report No. B.234. (A.M. File C.M.S. 82/II).

information was expressed as curves on which the radius of the target at which it was desirable to use two or more aiming points was indicated. This note, which was passed to Intelligence for their use, is included in the series of Internal Memoranda as Bomber Command O.R.S. No. M.112.(1)

At a later date the Commander-in-Chief requested the O.R.S. to make an appreciation of the effort required to destroy all the remaining built-up areas in Germany of a size of over 100 acres. The irregularity of these made the use of the curves referred to in the previous paragraph rather difficult and instead of this, circles were drawn on Kodatrace showing density contours for raids of different sizes with the accuracies appropriate to different marking techniques. With the aid of these the number of aiming points on each built-up area and the required size of the attacks were determined and, from this, the necessary tables were drawn up. The note prepared, which was to be used in an appraisal by the Air Staff of the economic effects of carrying out such a campaign was issued in the Internal Memorandum Series as Bomber Command O.R.S. No. M114. (2)

Following on this a further mathematical attack on the problems of the optimum size of a raid was made in which the proportions of the tonnage dropped was divided into that necessary for the required amount of destruction, the additional quantity hitting the destroyed area and thus wasted in overhitting, and that which fell outside the area of the target that was destroyed. Curves indicating the proportions in each of these categories as the tonnage dropped increased were produced for various combinations of random and systematic error. This work, completed too late to be used before the conclusion of hostilities was published as a Bomber Command O.R.S. Report.

Besides these larger questions small problems often arose in the field of bomb performance and force requirements which are too numerous to detail but it is probably of interest to note two which though never actually leading to operational use illustrate the diversity of such questions. The first related to chemical warfare and, starting from a paper by the Army School of Chemical Warfare at Porton on lethal densities, full details of bombloads and force requirements for a full-scale gas retaliation on German cities was prepared and incorporated in operation orders. The other which cropped up in September 1944 and of which no record is kept concerned the dropping of food from high altitude into Warsaw.

(1) "Planning Chart for Area Targets, 25 November 1944" Bomber Command O.R.S. Memo. No. M.112. (A.H.B./IIH/241/22/3).
(2) "The Relative Effectiveness of I.B. and H.E. in Attacks on Previously Damaged German Cities." Bomber Command O.R.S. Memo. No. M114 (A.H.B./IIH/241/22/3).

CHAPTER 7

WEAPON EFFECTIVENESS AND GENERAL EFFECTIVENESS

Introduction

The power of a bomb to damage or destroy a particular type of target can be studied in several different ways. The most straightforward way is to detonate the bomb in proximity to a sample target and to examine the results. Another method is to measure the effect of various blast pressures on the target and then measure the strength of the blast wave at various distances from the bomb. An entirely different method made possible by the use of reconnaissance photography is to measure the damage caused in an actual raid and to determine if possible the particular bomb or the density of bombs which caused it.

The experimental approach has been exploited for many years but it has serious shortcomings in that the types of target attacked are legion and even against the same target the result can vary considerably according to the relative disposition of target and bomb and a large number of experiments are required before a reliable answer is obtained. Further more, particularly in the case of fire bombs, the extrapolation from single targets to a conglomeration, from experimental to operational conditions, is fraught with danger.

As soon as sufficient damage was caused in Bomber Command raids to be visible on post raid reconnaissance photographs the other approach was made available. It soon became evident, however, that satisfactory results could not be obtained with anything short of a full-scale analysis of the photographs in which the damage was made. Even so the results was subject to statistical variation to such a degree that a very large body of data was required before the result could be regarded as reliable.

With the increase in the tempo and success of the bomber offensive the necessary amount of data began to accumulate but at the same time it became clear that it was beyond the scope of the O.R.S. to deal with it. The detailed analysis was in fact beyond the scope of 'K' Section, Central Interpretation Unit, whose prime purpose was the appreciation of the damage from the operational point of view, a task which was already straining their resources. At this time, however, the Research and Experiments Department of the Ministry of Home Security was interested in the detailed analysis of damage photographs as a means towards assessing the economic effects of a raid. It was therefore suggested to them that an extension of their work would also provide such answers as could be obtained on the weapon effectiveness question.

Their collaboration was enthusiastic and complete and from that time most of this type of research emanated from R.E.8. It was a particularly appropriate arrangement since the Research and Experiments Department already contained many men of experience in bomb performance in which subject they had initially been interested from the defence aspect. Close liaison with this department was maintained in

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order to ensure that their researched should be made with a full appreciation of the operational conditions involved and they were put in touch with 'N' Section, Central Interpretation Unit, whose studies of bombfall in night photographs proved invaluable in such matters as the pinpointing of particular bombs or the study of incendiary bomb density. After this stage the role of the O.R.S. became to a large extent passive although from time to time it was able to offer active assistance as, for instance, in providing an alternative method of assessing bomb densities from a study of night photographs.[1]

Bomb Performance

Within the Command it was now the function of the O.R.S. to maintain close liaison not only with R.E.8 but with all the various bodies studying bomb performance in order to keep the Air Staff in touch with new developments and to advise them, in collaboration with the Armament Branch, on the types and combinations of bombs which were most efficient against the various types of target attacked. This involved an appreciation of the stowage characteristics of each type of aircraft with respect to each type of bomb which were far more capricious than most people outside the Command realised. Before 1944 the target to be studied was the heterogenous complex presented by the German town and the manner in which the growing knowledge of the effectiveness of bombs was translated into practical recommendation is well illustrated in Bomber Command O.R.S. Report No. 76.[2] Another use to which this knowledge was put was in devising a method by which a first phase estimate of the amount of damage likely to have been caused in an attack where night photographs were available but circumstances caused a long delay in obtaining satisfactory post raid cover.[3]

In the field of incendiary bomb effectiveness the work was enlivened by the appearance of a controversy which engaged the attention of the experts on all aspects and which had a bearing not only on the design of incendiary weapons but also of the operations in which they were used. It centred about the question as to the relative contributions of primary fires and fire-spread to the overall effect of an incendiary raid. Although finally submitted to a forum of the Royal Society the question remained controversial. The academic questions involved may or may not have been important but clearly since they led to no outstanding indication one way or another and since the practical matters involved were of operational urgency they could not wait for the end of this apparently interminable discussion. Having been closely connected with the research relating to this question from the

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(1) 'Relation between the Centre of a Night Photograph and the Fall of Bombs.' Bomber Command O.R.S. Report No. 71.
'A Method of Estimating the Effective Weight of Attack.' Bomber Command O.R.S. Report No. 72. (A.H.B./II/39/1).

(2) 'The Relative Efficiency of Bomb Loads for Attacks on German Towns'. Bomber Command O.R.S. Report No. 76. (A.H.B./IIH/258/1/155).

(3) 'Statistical Assessment of the Results of a Night Bombing Raid on a German Town using Night Photographic Evidence of the Distribution of Attack.' Bomber Command O.R.S. Report No. 81. (A.H.B./II/39/1).

very beginning the O.R.S. was able to make a separate appraisal so that the Command could take a firm stand on the choice and disposal of weapons. There has been no evidence produced since then to indicate that they were seriously misled.

The principle of assessment having been established no more was published on this subject but the frequent changes in stowage characteristics brought about constant revision of the result which was issued from time to time by the Air Staff as operations orders.

The standardisation of bombloads in this manner and the resolution of the Command views on the types of bombs preferred greatly assisted the work of bomb provisioning and as time went on the Command, actively assisted by the O.R.S., took a more and more definitive part in the policy underlying future production. This problem became increasingly complex as the bomber force became involved in the close support of ground forces since this presented a greater variety of potential targets.

Indeed the whole problem of bomb performance became more urgent and less straightforward with the advent of this phase since the amount of experience on the effectiveness of various types of bombs against the many different types of target involved, which included guns, minefields, wire, troops in the open, troops in hutted camps, troops in slit trenches, ammunition dumps, tanks and other vehicles, was strictly limited. However, the work of the experimental establishments, of the mathematicians, of the photo interpretation experts and such information which accrued from ground survey in re-occupied territory was closely followed up so that the latest opinions on all these matters were always available at the Command and when the time came to attack these targets firm recommendations could be made. These were first made on a day to day basis but as the tactical target programme became more clear it was possible to crystallise this matter by drawing up a list of bombloads with fusings for each type of aircraft and for various routes appropriate to all the types of targets likely to be attacked. This was issued as an operations order so that by reference to a brief code it was ensured that the most efficient loading was used throughout the Command.

One ~~extremely~~ important aspect of H.E. bomb performance upon which it was extremely difficult to obtain quantitative information was the question of what proportion failed to explode. Full scale experiments likely to produce statistically satisfactory results were prohibitive in effort and cost and such indications as accrued from other trials suggested that the proportion was very small indeed. On the other hand the impressions gained during ground survey of targets in the Mediterranean theatre when these were eventually occupied did not support that view. Unfortunately neither of these sources of data were sufficiently complete to crystalise the impressions gained into even approximate figures.

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When a fairly satisfactory method of estimating the number of bombs falling on a given area had been devised using night photographic evidence it seemed that a comparison of such numbers with the craters detected within the same area on post raid reconnaissance would be a fruitful line of research. This was followed up [1] but the result was not satisfactory for two reasons. The estimate of bombs falling in the area was itself only approximate and there was at that time a strong suspicion that even the most assiduous examination of post raid photographs often failed to reveal all the impact points of exploding bombs. All that could be said was that the average failure rate of medium capacity/general purpose bombs did not exceed 24 per cent and that of high capacity bombs was less than 18 per cent.

Later when all H.E. bombloads were being frequently used it was possible to pick out strings of craters evidently forming isolated sticks and the average number in such sticks was compared with the average number of bombs carried per aircraft.[2] Again the result was subject to doubt owing to the slight variation in the numbers carried per aircraft in any given attack and also to the possibility of gross instability which could divorce the point of impact of a bomb from the others out of the same aircraft without necessarily preventing its detonation. It was, however, more definitive than the earlier results and suggested that about 10 per cent of medium capacity/general purpose bombs failed to explode. Although this figure was still regarded in some circles with scepticism it was the figure normally used in planning the weapon requirements of future operations.

<u>Ground Survey in France</u> In September 1944 a unit known as the Bombing Analysis Unit (B.A.U.), commanded by Group Captain E.S. Drury and with Professor Zuckerman as Scientific Director, was formed with a directive to carry out ground surveys of areas which had been subjected to bombing in support of the army. This was to include the bombing of tactical targets such as bridges and railways as well as close support operations and although not strictly within the terms of reference the bombing of V-weapon targets was to be included. On the orders of the Commander-in-Chief two members of the O.R.S., later joined by a third, were attached indefinitely to this mission and the Officer-in-Charge O.R.S. spent intermittent periods with it.

The B.A.U. was based at St. Germain-en-Laye, near Paris, and the field personnel were divided into parties consisting of several research officers backed by an administrative officer and such personnel, transport and equipment as was required to render the party

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(1) 'Adjustments of Measured Densities for Crater Spacing' Bomber Command O.R.S. Memo. No. M.118. (A.H.B./IIH/241/22/3).
(2) 'A Note on the Proportion of MC/GP Bombs which fail to explode.' Bomber Command O.R.S. Report No. 101. (A.H.B./II/39/1).

self-contained. They were dispatched to various regions in France with instructions to set up semi-permanent field headquarters at a convenient centre and to study selected targets within easy reach (up to 50 miles) of that headquarters. The first field headquarters were located at Le Havre and St. Malo with projected ones at Caen, Calais and Brussels.

The Bomber Command O.R.S. personnel were assigned to and put in charge of the Le Havre party since this region included many targets attacked by Bomber Command including bombing in support of the battle of Le Havre. This party formed up in England and proceeded direct to Le Havre via the battle areas of Villers Bocage, Caen and Cagny and set up headquarters in a large but battered villa in the northern suburbs of the town about ten days after the occupation from which teams were sent out to make the following field studies.(1)

(a) Detailed survey of E-boat pens (B.A.U. Report No. 5).

(b) General Survey of defence positions in front of Le Havre (B.A.U. Report No. 27).

(c) Detailed survey of two permanent field gun positions (B.A.U. Report Nos. 15 & 26).

(d) General survey of coastal batteries between Le Havre and Abbeville (B.A.U. Report No. 31).

(e) Detailed survey of two coastal battery positions near Le Havre (B.A.U. Report No. 16 and 25).

(f) Detailed survey of a permanent barracks area known as the Hotel Pour Passagers north of Le Havre (B.A.U. Report No. 13).

(g) Examination of a number of incidents of tail instantaneous fused bombs on warehouses in the harbour (B.A.U. Report No. 28).

(h) Detailed survey of a railway viaduct at Merville which had been attacked by bombs and rockets (B.A.U. Report No. 32).

For most of these studies the teams were based on Le Havre but for the more northerly coastal battery surveys it was necessary to find a subsidiary base at Dieppe. In the case of the detailed surveys full particulars of the construction of the targets and subtargets was obtained as well as of the bomb damage inflicted and an accurate plot of all bombs in the vicinity of the targets was made. Local inhabitants present at the time of the attacks were interrogated in order to discover such information on the effects of the bomb which were not apparent from a physical survey. As the field surveys were completed the data obtained was analysed with a view to assessing the effectiveness of the bombing as a whole and wherever possible the effectiveness of individual weapons. A draft report was then written incorporating all the data from physical survey and interrogation including detailed drawings, the results of the analysis and the conlcusions reached, and forwarded to the B.A.U. headquarters for editing and publication.

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(1) Copies of the B.A.U. Reports may be found in A.H.B./IIS/136/1-32.

In October 1944 one of the Bomber Command O.R.S. officers from the Le Havre Field Headquarters was detached to take charge of a new field headquarters based on Caen with instructions to study the results of Operations Goodwood, Totalise and Tractable which were carried out in close support of the Army's advance from Caen to Falaise. Owing to the insufficient data received from Twenty-first Army Group on the ground aspect a completely satisfactory study was impossible but the information and indications obtained ~~are~~ were recorded in a Bomber Command O.R.S. Memorandum [illegible]

In addition the following detailed studies of particular targets were made:-

(a) Detailed study of the effect of heavy bombing on a concentration of tanks (B.A.U. Report No. 22).

(b) The effect of bombing on a coke oven plant at Colombelles (B.A.U. Report No. 11).

(c) The distribution of weapons and their effect in a rocket attack on a mine-head buildings at Soumont St. Quentin (B.A.U. Report No. 23).

(d) The effect of fighter-bomber attacks in a series of German military headquarters (B.A.U. Report No. 12).

In November a second Bomber Command O.R.S. officer from Le Havre was temporarily detached to take charge of a study of the effects of air attack on the large V-weapon site at Watten working from the base at St. Omer. (B.A.U. Report No. 33).

During this period the B.A.U. was working closely with the United States Air Evaluation Board (U.S.A.E.B.) and most of the field parties included officers from that organisation. The problem of target selection was studied in collaboration with their Headquarters staff by a Committee composed of members of the B.A.U. and the U.S.A.E.B. of which the Officer-in-Charge Bomber Command O.R.S. acted as joint chairman.

By the end of January 1945 all the studies listed above were complete and the reports ready for editing and publication. The Commander-in-Chief, Bomber Command, decided that the time had come for his O.R.S. officers to transfer their attention from tactical targets to those of a more strategic nature since strategic bombing had been the first and still remained the most important role of the heavy bomber force. Such targets however were outside the terms of reference of the B.A.U. and it was therefore necessary at that stage for the O.R.S. officers to sever their connection with that body.

One research officer was withdrawn completely and the remaining two were attached to the British Bombing Research Mission. This Mission was planned on an ambitious scale with a view to surveying targets in Germany as soon as they became available for inspection. At the beginning of 1945 it had already set up an advanced headquarters near Paris with a skeleton administrative staff and pending the availability of targets in Germany it was providing liaison, transport and

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base facilities to various investigating teams who were working on French targets. The scheme here was different from that within the B.A.U. in that an investigating team was not self-supporting but depended for accommodation and supplies on such military formations as were found in the neighbourhood of the target. Although preliminary introductions were dispatched from the B.B.R.M. Headquarters it often occurred that these had not reached the relevant officials by the time the party arrived and it was then necessary for the investigating team to make its own arrangements. This gave rise to temporary difficulties but also to many interesting and amusing situations.

Under these auspices the remaining two O.R.S. officers studied three factories in France which had been subject to attacks by Bomber Command with a view to assessing the effects of the bombing both as to physical damage and production loss and to obtain such information on weapon effectiveness as was available. Detailed plots of damage and bombfall were made, production records were scrutinized when available and the management of the factory together with people living nearby at the time of the attack were interrogated. The results of these investigations were forwarded to Bomber Command O.R.S. and are recorded in the following papers:-

(a) Bomber Command O.R.S. Report No. S.228 – 'Ground Survey of the Effects of Air Attack on the Gnome and Rhone Works at Gennevilliers.' (1)

(b) Bomber Command O.R.S. Report No. S.229 – 'The Effect of Air Attack on the B.M.W. and G.S.P. Works at Albert.' (2)

(c) Bomber Command O.R.S. Memorandum – 'The Effect of Air Attacks on the and Primagaz factories at St. Pierre de Corps near Tours.'

The second of these is particularly interesting since it includes observations on the performance of 12,000 pound heavy capacity bombs. The third was not published as an O.R.S. report because the absence of records or of executives who had held office during the occupation made a complete study impossible.

Ground Survey in Germany

By the beginning of March when these studies were completed it had become possible to consider targets in Germany and arrangements were put in hand for the O.R.S. team, reinforced by two further O.R.S. officers and an American officer from the Ministry of Home Security, to proceed to Aachen. The party left on 9 March and were away ten days.

This was the first attempt made on a general study of the effects of bombing on a town as a whole and the investigation was largely exploratory. The general situation was naturally chaotic since the main concern of the occupying force was to facilitate the movement of supplies to the front and efforts at reconstruction of the municipal

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(1) A.H.B./IIH/241/22/14.
(2) A.H.B./IIH/241/22/14.

and industrial life of the town and the entertainment of non-operational personnel were subjugated to this overriding necessity. Add to this the fact that only one member of the team spoke German and it will be seen that conditions were in general against a highly scientific and quantitative assessment being made. However a good approximate picture was obtained and perhaps more important still a very good idea of the difficulties to be encountered, the general set-up and the sort of information which could be expected under these circumstances was obtained. A report on the investigation was rendered to Bomber Command (1) and to the B.B.R.M. who published it as B.B.R.M. Report No. F.16.

During April the O.R.S. team, again reduced to two, were attached to a B.B.R.M. team operating in Krefeld to make a similar study of Krefeld and Uerdingen. Conditions were here somewhat better than in Aachen but with the enemy just across the river full freedom of action was somewhat impaired. Here, however, any attempt to make a physical survey of damage beyond taking representative photographs was frankly discarded and a more orderly selection of firms and programme of interviews was instituted and the use of written questionnaires was introduced. There was an United States Strategic Bombing Survey team also working in Krefeld at this time with whom close contact was kept and it is certain that both teams benefited mutually from each others experiences as well as from their own. The result of the study (2) is a little more quantitative than in the case of Aachen but the amount of reliable statistics found still remained small.

It was not until the end of April that any really important industrial cities were occupied, in fact the liquidation of the Ruhr pocket took place towards the end of the visit to Krefeld. By the time the Krefeld report was written preparations for a properly equipped ground survey unit were coming to fruition and on 11 May 1945 the Bomber Command Bombing Research Unit came into being. The two O.R.S. officers already operating were joined by a third and were backed up by a completely self-contained staff of drivers, interpreters, aircrafthand and a cook equipped with transport and everything necessary to work as a separate unit. This was headed by a group captain and administered by an adjutant, the whole unit being attached for administrative purposes to the B.B.R.M. which later became amalgamated with the B.A.U. to form the British Bombing Survey Unit.

The first mission of this new unit, a survey of the effect of bombing on Essen, was marred by tragedy. The commanding officer, accompanied by a driver and interpreter, set off to make preliminary arrangements for the accommodation of the unit and on his way back to Paris where the unit had formed up was involved in a road accident and killed. The interpreter and driver were put out of action and further

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(1) A.H.B./IIM/a1/6a, June 1945.
(2) 'Brief Survey of Effects of Air Attack on Krefeld-Uerdingen', Bomber Command O.R.S. Report No. S.232. (A.H.B./IIH/241/22/14).

to complicate matters the adjutant was posted at short notice. However the unit set out for Essen on 17 May and began operating on 19 May. Later the research team, working under difficulties owing to the loss of one of their interpreters were strengthened temporarily by the advent of the Officer-in-Charge O.R.S. and one other officer.

In Essen the written questionnaire technique was extended and this together with the experience gained in the earlier studies resulted in a more satisfactory investigation.[1] Krupps which, of course, dominates the industrial fabric of Essen was dealt with separately and a fairly detailed inquiry involving the collaboration of most of the higher executives of the concern was made.[2] By this time the general situation was improved by the cessation of hostilities and more statistics particularly with regard to the municipal life of the town were obtained. ~~The result of the investigation appears in Bomber Command O.R.S. Reports No. S.233 - Essen General (1) and No. S.235 - Krupps. (2)~~

During the survey of Essen the three latest additions to the research staff were withdrawn and the one was replaced. The new adjutant and commanding officer also arrived about this time.

It was observed that the three other towns in the Ruhr which were to be surveyed were within an hour or less by car from Essen and it was decided that much time would be saved if instead of moving the unit to each town, the work was carried on from the quarters in Essen which were very satisfactory particularly from the point of view of office space. This also enabled more than one target to be worked at one time without splitting up the unit.

From that time on the following routine was instituted. First, an advance officer visited the town under review and made arrangements for an office in the military government and lunch for the period during which interviews would take place, at the same time arranging for the distribution and subsequent collection of written questionnaires. With each successive target these questionnaires were modified and enlarged so that they provided very good information on the damage sustained and the fluctuation in production of most of the larger firms in the town. They were eventually extended to take in the matters of interest concerning the municipal offices of the city so that interviewing could be concentrated on the very large firms and such amplification of the questionnaires as was considered necessary. After a week or ten days two research officers accompanied by interpreters collected the questionnaires, examined them, selected personalities for interview, and carried out their interviews in the office provided by the military government. The third research officer was meantime analysing the data collected on the previous target and writing up the report. This scheme was made possible only by the keenness and versatility of

/interpreters

(1) 'Effect of Air Attack on Essen and District.' Bomber Command O.R.S. Report No. S.233. (A.H.B./IIH/241/22/14).
(2) 'Effect of Air Attack on Krupps Works - Essen.' Bomber Command O.R.S. Report No. S.235. (A.H.B./IIH/241/22/14).

interpreters and clerks who soon learned to perform the duties of statistical clerks in between their normal duties. In this way everyone was fully employed all the time and the time taken for the whole task considerably shortened.

The other towns in the Ruhr which were investigated were Bochum,[1] Dortmund[2] and Dusseldorf.[3] Whilst operating in the Ruhr a number of synthetic oil works which had been attacked by the Command were covered and the data were dispatched to the O.R.S. where they were analysed from the operational and planning aspect[4] and then handed over to the B.B.S.U. who were concerned with the economic aspect. The Ruhr is, of course, concerned to a large extent with heavy industry and the importance of attack on underground services with medium cased H.E. in such an area was constantly being observed. It appeared important to bring this to immediate notice and an interim report on this subject was submitted.[5] ~~(O.R.S. Memorandum No. M.115).~~ ~~(5)~~

During the examination of Krupps it was discovered that a large number of pistols from unexploded bombs had been retained and the bomb-disposal experts were still available. It was considered desirable therefore that an armaments expert should examine these pistols and discuss the question of unexploded bombs with the bomb disposal experts and also to see the A.R.P. personnel of surrounding districts particularly the oil targets with a view to discovering the causes of bomb failure, the incidence of which was found to be high. Accordingly an armament officer from Bomber Command was attached to the Bomber Command Bombing Research Unit. ~~and his findings are recorded in ?~~

Towards the end of July the unit moved to Hamburg and from that base the City of Hamburg itself[6] and the port of Bremen were studied.[7] About a month later the last move from Hamburg to the B.B.S.U. Headquarters near Hannover was made and from ~~this base~~ there Kassel[8] and Hannover[9] were surveyed. In the case of Bremen and Kassel it was necessary to detach a small team from base during the interview period.

The original programme of targets to be dealt with included two further towns, Nuremberg and Friedrichshafen. By this time, however, the Japanese war had come to an end and the B.B.S.U. had embarked on a new approach to the economic study of bombing of towns using largely data collected by the United States Strategic Bombing Survey. It was therefore decided to curtail the original programme and call a halt when

/Kassel

(1) 'Effect of Air Attack on the City and District of Bochum.' Bomber Command O.R.S. Report No. S.234. (A.H.B./IIH/241/22/14).
(2) 'Effect of Air Attack on the City and District of Dortmund.' Bomber Command O.R.S. Report No. S.238. (A.H.B./IIH/241/22/14).
(3) 'Effect of Air Attack on the City and District of Dusseldorf.' Bomber Command O.R.S. Report No. S.239. (A.H.B./IIH/241/22/14).
(4) 'Effect of Air Bombardment on Synthetic Oil Plants in the Ruhr.' Bomber Command O.R.S. Report No. S.245. (A.H.B./IIH/241/22/14).
(5) 'The Importance of Heavy Cased H.E. in Attacking Industrial Areas, 12 July 1945.' Bomber Command O.R.S. Memo. No. M.115. (A.H.B./IIH/241/22/3).
(6) 'Effect of Air Attack on the City and District of Hamburg.' Bomber Command O.R.S. Report No. S.240. (A.H.B./IIH/241/22/14).
(7) 'Effect of Air Attack on the City and District of Bremen.' Bomber Command O.R.S. Report No. S.241. (A.H.B./IIH/241/22/14).
(8) 'Effect of Air Attack on the City and District of Kassel.' Bomber Command O.R.S. Report No. S.242. (A.H.B./IIH/241/22/14).
(9) 'Effect of Air Attack on the City and District of Hanover.' Bomber Command O.R.S. Report No. S.243. (A.H.B./IIH/241/22/14).

Kassel was completed. Since the domestic staff of Bomber Command Bombing Research Unit was not required at Hannover these were sent back to England and when the draft reports on Hannover and Kassel were complete the unit was disbanded, handing over most of its transport and all its documents to the B.B.S.U. These documents included production data on submarines at Kiel which had been collected while the unit was at Hamburg. Together with similar data relating to Hamburg and Bremen this covered all the submarine production of Germany with the exception of Danzig.

Before leaving Germany the [redacted] Officer-in-Charge O.R.S. and one research officer visited Berlin and saw the executives of a number of important firms. No attempt at a survey was made but the visit produced some interesting observations.(1) ~~which are recorded in Bomber Command O.R.S. Memorandum No. M.116.(1)~~

(1) 'Impressions concerning the Effects of Air Attacks Gained in a Brief Visit to Berlin, 21 November 1945.' Bomber Command O.R.S. Memo. No. M.116. (A.H.B./IIH/241/22/3).

CHAPTER 8

NAVIGATION

Early Analyses

During the summer of 1941, Bomber Command crews were beginning to obtain night photographs in sufficient quantities to show that, except under very favourable conditions, not only were they not finding their targets, but a high proportion of photographs were plotted so far from the target that it was quite certain that the difficulty was not only one of visual target identification. The accuracy of navigation was also inadequate. A preliminary analysis of navigator's logs, in an endeavour to determine the accuracy of navigation, was first undertaken towards the end of 1941. As a first step, the investigation was limited to determinations of the use made of the available fixing aids (loops and astro) and the inter-relations between the number of fixes taken, the time of search for the target, and location of the target. This analysis disclosed a weak correlation between time of search and location of the target and a weak inverse correlation between time of search and the number of fixes taken. It was soon realised that full-scale systematic analysis would require considerable scientific effort which was not then available. Gee had been tried out experimentally over Germany in 1941, and it was then withdrawn pending full-scale introduction in the spring of 1942. It was considered that Gee would so revolutionise navigation as to render it infinitely preferable for the available O.R.S. effort to be applied to the work on Gee and visual identification of the target, rather than to the study of navigational methods which would soon become obsolete.

By the summer of 1942 there was ample confirmation that Gee had revolutionised navigation, and although the problem of visual identification was still pressing, bombing results within Gee coverage, although still leaving much to be desired, showed an improvement. On raids of deep penetration beyond Gee coverage, however, there was little improvement. Since there were many targets beyond Gee coverage, it was felt that investigation into the methods employed by operational navigators would yield useful results. It was particularly desirable to find out whether navigators were making the most of their opportunities to determine winds and fix positions while still within Gee coverage. Also, bomber losses were beginning to rise and the need for greater concentration in time and space in order to minimise the effects of G.C.I. and flak, was beginning to be appreciated. Ability to increase concentration depended to a great extent on the accuracy of navigation, and it became important to determine the distribution of our aircraft in space during an operation. Additional O.R.S. staff having now arrived, it was decided to investigate the accuracy of navigation by means of a detailed study of navigator's logs.

The first objective of these early investigations was to discover what accuracy could be achieved in determining the actual positions of a number of aircraft at a given time. If this could be done with reasonable accuracy it was hoped to obtain information on:-

(a) Concentration of the force and its effect on interception and loss risk.

(b) The quality of navigator's work and steps which should be taken for improvement.

(c) The performance and utilisation of aids to navigation.

It did not take long to develop a technique of analysis by which the actual position of a given aircraft at a given time could be determined with a useful degree of accuracy, and the first full-scale investigation yielded valuable information on the concentration achieved en route and convinced the Air Staff that there was much scope for improvement. The technique developed was the basis of all subsequent analyses which continued until 1945, and were the backbone of most of the navigational researches undertaken by O.R.S. These researches included investigations into the performance and utilisation of Gee, Astro, Air Position Indicator (A.P.I.), H2S, and the Ground Position Indicator (G.P.I.), as well as the operational accuracy of wind finding by navigators. This last investigation led to the development of the wind broadcasting scheme, which was introduced into operations during the winter of 1943/44, in which the O.R.S. played a major part in analysing the effectiveness of the scheme in its various stages. In the autumn of 1944 it was found possible to start research into navigational training problems in Heavy Conversion Units and Operational Training Units.

In addition to the investigations mentioned above, many incidental problems were dealt with. Some of these were short-term questions which called for no special mention, but five of them were of a larger scale and of sufficient interest to warrant description. These five were:-

(a) The method of navigation on a climb.
(b) Route marking investigations.
(c) Snap alterations of course to regain track.
(d) Investigations into the accuracy of met. wind forecasts.
(e) The analysis of the accuracy of log and chart keeping.

The first log analysis which dealt with the attack on [redacted] Mainz on 11/12 August 1942 had the objective of discovering and listing all the data which could be obtained from a thorough and systematic examination of navigator's logs, particularly data concerning concentration and the relation between the degree of concentration and interception risk. The method of analysis~~, which was described in Bomber Command O.R.S. Report S.73,~~ ~~(1)~~

~~(1) A.H.B./II/39/1/1.~~

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consisted essentially of plotting positions of a representative sample of aircraft at a pre-selected time en route. The actual positions of aircraft at these chosen instants was determined from the evidence available in the logs combined with the photographic evidence produced at bomb release. The track of each aircraft was re-plotted from a reliable fix nearest the selected time, using the course and speed quoted in the log but substituting for the wind used by the navigator the average of the winds found by all the crews at the relevant height on that section of the route. Cross checks were obtained wherever possible by forward and backward plotting from fixes taken earlier and later respectively than the time selected for the plot. These 'concentration plots', as they became termed, gave instantaneous pictures of the state of the operation at various stages of its fulfilment.

The first necessity was to examine the error likely to be made in plotting aircraft positions by these methods, since it was apparent that the conclusions might to some extent be affected by the accuracy of the plotting method. This analysis of probable plotting errors had to be based on estimates of errors of individual processes, which could not all be checked by direct analysis but which were derived after discussion with the Royal Aircraft Establishment, and were the most reasonable which could be made in the circumstances.

The results of this investigation ~~were published in Bomber Command O.R.S. Report No. S.73 and~~ showed that aircraft positions could be plotted with a probable linear error of three to eight miles depending on the range at which the positions are required.(1) The figure of eight miles, for example, referred to Frankfurt or to places at a similar range, It should be borne in mind, however, that these conclusions were framed at a time when Gee was almost universally used for fixing up to the limits of its range and before the operational use of H2S had become general. With the introduction of H2S, fixing accuracy was no longer dependent on distance from base, and plotting errors were therefore reduced. While the errors quoted were too large to permit analysis from navigator's logs of the accuracy of such aids as Gee, they were much smaller than astro position-line errors and could be allowed for in the derivation of astro accuracy by log analysis.

The Mainz analysis gave figures for concentrations (both en route and over the target), widths and length of the bomber stream at various sections of the route, rates of passage across selected fronts, the numbers and types of fixes taken and the average heights and airspeeds maintained. It also lent confirmation to the presumption that high losses were associated with low concentration. In view of the general interest aroused throughout the Command by this report (particularly by the concentration plots), further analyses on similar lines were made, covering three raids, those against

(1) 'Analysis of Navigation on Night Bomber Operations – Mainz, 11/12 August 1942.' Bomber Command O.R.S. Report ~~Frankfurt~~ No. S.73. (A.H.B./IIH/241/22/14).

Frankfurt on 24/25 August, Kiel on 13/14 October and Duisburg on 20/21 December 1942, reference to which is made in Bomber Command O.R.S. Memoranda M. 1 to 3 respectively.(1)

The most important conclusions resulting from these four investigations were:-

(a) That achieved concentration both en route and over the target, were only a fraction of those planned.

(b) That high interception rates were associated with low concentrations, although this latter relation appeared to hold only up to a limiting concentration of about one aircraft per 20 square miles en route, above which no further advantage appeared to be gained.

These conclusions, their method of derivation and associated results were discussed in Bomber Command O.R.S. Memo Nos. M4 and M5.(2)

Many crews on bombing operations adopted a policy of weaving over enemy territory in order to minimise the risk of fighter attacks, and in view of the possible deleterious effect of this practice on accurate navigation an attempt was made to determine from the analysis of logs the amount of weaving actually carried out. The method used, which is described in Bomber Command O.R.S. Memo. M6, was to compare the actual distance between the mean positions of the force at two consecutive plotting times (the mean position is taken as the centre of gravity of the plot) with the expected distance based on the mean ground speed of the whole force which was derived from recorded airspeeds and true winds. The mean percentage time loss, due to weaving, for the four raids analysed above was found to lie within the limits of four per cent and 12½ per cent.

An analysis of navigator's logs which was continued in 1943 was helped greatly by the attachment of tour expired navigators which was arranged by the Navigation branch of the headquarters. With the help of this team of plotters it was possible to deal with all plottable logs and not merely with a sample as in the previous work. Accordingly, during 1943 analyses covering three large scale raids against Nuremburg, Hannover and Kassel in August, September and October respectively, were carried out. The results were published in Bomber Command O.R.S. Reports Nos. 82, 86 and 89.(3)

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(1) A.H.B./IIH/241/22/3.

(2) A.H.B./IIH/241/22/3.

(3) These three reports are to be found in A.H.B./IIK/46/468.

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The O.R.S. concentration plots quickly became popular with the individual groups, who adopted or modified the system to their own use and mostly succeeded in producing plots for all major operations by the end of 1943. These were mainly useful only to the group concerned since the method of plotting and the times selected differed for the various groups. The O.R.S. tried to secure a unified system and simultaneous plotting times for all groups in order that more general conclusions might be drawn from the results. Unfortunately, however, they were unable to achieve this result.

In addition to the general concentration and timing problems covered in the analyses discussed above, special attention was paid in the last three investigations to the problem of wind determination and use, because it was becoming apparent that lack of uniformity was causing considerable scatter of the force once it proceeded beyond Gee range. The analyses showed that three types of winds were used by navigators in about equal proportions:-

(a) Winds found en route,
(b) Met. forecast winds,
(c) 'Compromise' winds.

The reports emphasised the need for uniform practice which finally resulted in the introduction of the broadcast wind scheme. Another important finding was the lack of correspondence between the met. winds which were given to the different groups for the same section of the route, this leading to a further and quite unnecessary scatter. Met. procedure was subsequently amended and forecast winds unified. Other investigations which were made by the analysis of navigator's logs will be discussed later in this chapter.

Concentration plots produced at No. 5 Group in early 1944 had disclosed random and systematic track errors which were considered disappointingly large in view of the introduction of the wind broadcasting scheme. The O.R.S. was invited to investigate the reasons for these scatters. Navigator's logs were analysed, and it was found that the dispersion was due partly to misuse of the wind broadcasts (these are described on page 158), and partly to other factors. One of the most important of these was shown to be the systematic tendency on the part of many pilots to veer to port while ostensibly holding a straight course. This tendency to 'keep to the left' was discovered by re-plotting D.R. positions using the correct wind, and then measuring the direction of the error between each D.R. position and the corresponding Gee fix (the latter being assumed correct). It was then found that the large majority of these errors were in the same sense. A second cause of scatter was found to be inaccuracy in calculating courses. Log analysis showed that 30 per cent of navigators made errors of more than 2° in these calculations, and it was pointed out that such errors can seriously affect track-keeping accuracy on long, straight legs of the route. The third contributory cause of dispersion was found in the inadequate and

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inaccurate use made of route-markers by the main force, who commonly judged their distance by eye and estimated their bearing.

As a result of this analysis which was published in Bomber Command O.R.S. Memo No. M8,[1] the Air Officer Commanding No. 5 Group, who considered that many of the navigator's errors were due to inadequate illumination, instituted new and improved lighting in the navigator's cabin in the group's Lancasters.

The accuracy of calculation and plotting was subject to a much more detailed analysis in parallel with the No. 5 Group investigations. The raid selected was that on Magdeburg, on 21/22 January 1944. The results were fully described in a Bomber Command O.R.S. Report,[2] the chief conclusions being:-

(a) Two-thirds of all navigators made more than 10 errors per 100 processes,

(b) There was no significant difference between the performance of the experienced and inexperienced navigators in this respect.

The standard of time-keeping was investigated at the beginning of 1945 by the analysis of navigator's logs for the Hanover and Munich raids (5/6 January and 7/8 January).[3] The results, ~~published in Bomber Command O.R.S. Report No. 122,[3]~~ showed that the bad time-keeping on the Munich raid (where the met.winds were less accurate than on the Hannover raid) were partly due to failure to revise estimated times of arrival and to take the necessary action to correct timing immediately the estimated time of arrival had been revised. Many navigators made their effort to abide by the ordered times late in the flight, and as a consequence were forced to orbit in or near the target area. The other conclusions of this report dealing with wind finding problems are referred to in a later section of this chapter (page 158).

Astro Investigations

The analyses into the use of astro carried out by the O.R.S. were concerned with:-

(a) Investigation of the quantity of sights taken on operational sorties.

(b) Investigation of the quality (accuracy) of operational astro-sights.

The main purpose of the first type of analysis was to provide quantitative data on the use made of astro-sights and on the limiting factor of weather conditions at varying heights. ~~These investigations covered the period from September to December 1942 (inclusive)~~.

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(1) A.H.B./IIH/241/22/3.

(2) 'Note on the Standard of Log and Chart Keeping and Accuracy in Plotting and Calculations,' Bomber Command O.R.S. Report No. B.201. (A.H.B./IIM/a1/4a, March 1944)

(3) 'Analysis of Hanover Raid, 5/6 January 1945 and of the Munich Raid, 7/8 January 1945,' Bomber Command O.R.S. Report No. 122. (A.H.B./IIH/241/2/54(a)).

The information required for these analyses, unlike that considered hitherto, could not be extracted from navigator's logs and therefore had to be obtained from special returns which were made weekly by the different Groups and which showed, for each sortie, the average height flown, the number of astro-sights taken, and the conditions of star visibility observed during flight.

The results of this work were published in four Bomber Command O.R.S. Reports[1] covering the period September to December 1942 (inclusive) ~~No. 55, 60, 62 and 67, (1)~~ the last of which summarised the main conclusions as follows:-

(a) Astro-sights were taken on about 40 per cent of sorties.

(b) The average number of sights taken by navigators who made use of astro-navigation ~~was~~ four per sortie.

(c) Star visibility was good above 10,000 feet on about 50 per cent of operations, but at 1,000 feet and below it was good on only 20 per cent of operations.

It had originally been intended to continue this series of analyses in the spring of 1943, but this project was finally dropped in view of the heavy commitments arising from research into more recent navigational aids and because of the additional work imposed on the squadrons by the special returns.

The second form of astro-analysis was directed towards the determination of the average accuracy which could be expected under operational conditions from astro fixes with the Mark IX and IX A Sextants.[2] This work was undertaken at the request of the Director of Operational Requirements (Air Ministry) to assist him to decide the priority to be given to sextant development. ~~The method used and the results obtained were published in Bomber Command O.R.S. Report No. 75. (2)~~ The best estimated position of each aircraft at the moment of astro-observation was determined from the logs and charts and the position-line representing each star sight was obtained from the charts. The perpendicular distance from the estimated position to the astro position-line was then measured. This distance represented the error of the position-line. The error of the fix itself could seldom be measured directly, since comparatively few fixes were obtained from two astro-position-lines. The fix error was, however, derived theoretically from the position-line error, assuming an average angle of cut to 60°. It was necessary to restrict the analysis, geographically, to a zone including the area of Gee coverage and extending just beyond its limits; within this zone aircraft positions could be plotted with considerable accuracy, the effect of plotting errors being negligible compared with the astro errors. The great majority of sights analysed were made on homeward routes over the North Sea.

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(1) 'Analysis of Astro-Navigation Reports, September, October, November and October to December 1942.' Bomber Command O.R.S. Reports Nos. 55, 60, 62 and 67. (A.H.B./IIH/258/3/4).

(2) 'The Operational Accuracy of Astro-fixes.' Bomber Command O.R.S. Report No. 75. (A.H.B./IIK/46/46(B)).

The results showed that the probable error of an astro position-line was about 9¼ statute miles from the Pathfinder Force and 12½ miles from the main force. Assuming an average angle of cut of 60° these position-line errors correspond to fix errors at about 18 and 24 miles respectively. It was concluded that the 50 per cent error of an astro-fix under operational conditions was of the order of 20 miles. It is of interest to note that this is about two to three times the limiting errors, obtained by expert observers, on non-operational flights.

The two astro-investigations described in this section were the only analyses undertaken in this field by the O.R.S. The results obtained were of some assistance to the Air Ministry in deciding that no further work should be done on the design or production of a gyro-stabilised sextant.

Air Position Indicator ~~and Ground Position Indicator~~ Investigations

The Air Position Indicator (A.P.I.) was introduced into the Pathfinder Force (No. 7 Squadron) in March 1943, and a limited number were in service in April. Accordingly, a visit was made to the R.A.E. who were primarily responsible for the development of the instrument, on 2 April, to discuss the most suitable method of operational analysis of the accuracy of the A.P.I. As a result of this discussion it was decided that a useful check could be obtained on random errors by comparing the scatter of A.P.I. and non-A.P.I. winds about their respective means; it was agreed that the difference between the means would, if statistically significant, give an indication of the systematic error of the A.P.I., but it was considered unlikely that sufficiently large samples of winds would be available for such a test.

Following these discussions with the R.A.E., a visit was made to No. 8 Group to arrange for a supply of navigator's logs and to explain what A.P.I. recordings were required to be entered in the log to facilitate analysis of accuracy of the instrument. The only additional data requested were:-

(a) A record of A.P.I. readings before and after each reset.
(b) A record of the reading a bomb-release.
(c) A record of the reading over base, on return.

With the exception of (c) these recordings were those normally required by the navigator himself; hence the analysis laid practically no additional work on the crew and called for no special forms. The first logs analysed were for 23/24 April; and a further analysis was carried out early in June. The results were combined and sent to the Station Navigation Officer at No. 7 Squadron, which was at that time the only squadron equipped with sufficient A.P.I.s to permit useful analysis.

These early analyses were mainly confined to measurement of consistency of the mean A.P.I. winds found by the different navigators for the whole of the outward and homeward routes. These mean winds were derived by vector addition of the individual winds found over short sections of the route. Comparison of consistencies of these mean A.P.I. and non-A.P.I. winds was

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greatly in favour of the A.P.I. winds, and it was at once apparent that the A.P.I., when functioning correctly and used properly, would be a useful navigational aid. Since only a limited number of A.P.I. logs were available at this time (mid 1943) it was possible to investigate each in detail and to comment on the performance of individual navigators. These comments were then sent to the Station Navigation Officer at No. 7 Squadron to help the individuals concerned.

In July 1943 a further analysis was made by the same method of the logs of aircraft fitted with the A.P.I. By this time sufficient aircraft of No. 35 Squadron had been equipped to investigate the results obtained by navigators of this squadron as well as by those of No. 7 Squadron. The result confirmed the general accuracy of the A.P.I. and indicated that the systematic error of the instrument (obtained by comparison of the mean A.P.I. winds with the mean non-A.P.I. winds over the same sections and for the same height bands) was satisfactory small. It was also possible to indicate certain faults in the operational use of the A.P.I. and to make recommendations for improvement. This was done in the form of a letter to the Station Navigation Officer of No. 7 Squadron. The following were the chief recommendations.

(a) The A.P.I. should never be reset to any fix unless complete confidence is felt in the accuracy of that fix.

(b) Times and readings of the A.P.I. at each reset should always be logged.

(c) By a comparison of A.P.I. winds obtained either before or after a fix with the wind derived from the fix itself the reliability of the fix can often be checked.

(d) Little reliance can be placed on Gee-A.P.I. winds obtained over periods less than 15 minutes.

By August it had been established that the probable random error of wind determination with the A.P.I. was six miles per hour, corresponding to a probable error of three per cent of the air distance flown, at a mean timed air speed of 200 m.p.h. A first attempt was then made to write a general report on the operational performance of the A.P.I., but since no Lancaster results were available the enquiry was restricted; moreover, the method of obtaining systematic A.P.I. errors by comparison of winds proved to be insufficiently sensitive, owing to the restricted sample and the large random scatter of the non-A.P.I. winds about their mean.

By October A.P.I.s had been installed in Pathfinder Force Lancasters (No. 97 Squadron) and it was now possible to carry out an investigation on a considerably larger scale than any of the foregoing. The logs and charts of the Kassel raid on 22/23 October were chosen for this purpose, and the results

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~~were published in Bomber Command O.R.S. Report No. 89 (1) which was~~ were circulated to all squadrons by the Navigation Section at Headquarters Bomber Command.(1) The analysis showed that a marked deterioration in consistency of winds found with the A.P.I. had taken place since the summer; this fall was attributed to:-

(a) The use of too short or too long a period for wind-finding.

(b) Inaccurate recording or omission of the times of re-setting the A.P.I.

(c) Plotting and calculation errors.

(d) Errors due to de-synchronisation of the dead reckoning compass repeater on the A.P.I.

The values of mean A.P.I. and non-A.P.I. winds for the same sections of the route and the same height zones were found in some instances to be significantly different. But the directions of these differences bore no obvious relation to the directions of wind or track, and could not at the time be interpreted. It is probable that these anomalies were due to the fact that Lancaster results were not separated from those for Halifaxes and Stirlings as later investigations showed that the A.P.I., as originally installed in the Lancaster was subject to serious over-reading.

The investigation of operational A.P.I. results was continued at No. 5 Group in February 1944. The main object was to examine the systematic error which was now suspected of the A.P.I. installation in the Lancaster. The method of analysis was altered, since the mean winds comparison, previously used, had been found to be insufficiently sensitive. The new system adopted in the No. 5 Group investigations consisted broadly of comparing the A.P.I. (Air Mileage Unit (A.M.U.) component) [redacted] positions with corresponding air positions derived from a manual air plot for straight sections of routes in carefully selected logs.

The results of this analysis, which were published in a report circulated by No. 5 Group in March, confirmed the impression already gained that the A.M.U. component of the A.P.I. as installed in the Lancaster was subject to serious over-reading. The amount of this systematic error was found to increase from about three per cent of the air distance flown during the early stages of a flight to approximately eight per cent near the end. The reason for this progressive increase will be described later. It was found to vary somewhat in different aircraft.

As a temporary expedient pending the necessary modifications to the A.M.U. installation, it was recommended that all navigators should 'calibrate' their own A.P.I.s for the early, middle and late stages of the route, by keeping a very careful manual airplot over a distance of at least 100 miles

(1) 'Analysis of Navigation - Raid on Kassel, 22/23 October 1943.' ~~Bomber Command O.R.S. Report No. 89~~ - (A.H.B./II/39/1).

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and preferably - but not essentially - over a straight course, and comparing the air positions shown by the A.P.I. with those obtained from the air plot.

This systematic error of the A.M.U. component of the A.P.I. in Lancasters had also been discovered by the R.A.E. at about the same time (beginning of 1944) and was ascribed to:-

(a) Overheating of the unit in Lancasters, owing to its installation in close proximity to the cabin heating ducts.

(b) Insufficient air supply to the fan jacket.

The progressive increase in the over-reading tendency was doubtless due to an aggravation of the cause (overheating) with duration and height of flight. The modifications, suggested by R.A.E., entailed the fixing of a baffle-plate to deflect the hot air from the A.M.U. and the re-positioning of the vent for air supply to the fan jacket. These modifications which were performed by squadrons received considerable impetus from the report to which reference has been made, and a sufficient number of A.P.I.s had been dealt with by the end of March to allow the O.R.S. to analyse the residual errors of the modified sets. The results of this analysis[1] ~~, published in Bomber Command O.R.S. Report No. B207,~~ showed that the modifications had practically cured the systematic error, reducing it from plus 6·2 per cent (average for whole route) to less than plus one per cent of the air distance flown. The same method of determination was then extended to a sample of logs for Halifaxes, and disclosed no significant systematic error.[2] ~~(see Bomber Command O.R.S. Report No. B204).~~

The random errors of the A.P.I. were also examined using an extension of this same principle. The Air Speed Indicator air-positions, assumed to be 'correct' were superimposed and the scatter of the A.P.I. positions about this 'common' air speed indicator position was determined. This method ~~obviously~~ yielded a maximum value for the probable error of the A.P.I. since the air speed indicator position, though taken as standard and superimposed, ~~are obviously~~ were liable to small random errors. This determination ~~, which was published in Bomber Command O.R.S. Report No. 96,~~ showed that the probable random errors of the A.P.I. for both Halifax and Lancaster (modified installation) were less than three per cent of the air distance flown, and conclusively demonstrated the usefulness and accuracy of the instrument.[3]

The final A.P.I. investigations performed by the O.R.S. were carried out at No. 4 Group in April and May 1944. The object of these determinations was, inter alia, to discover by prolonged and detailed scrutiny of the logs of the wind-finding aircraft the operational use made of the A.P.I. (including the accuracy of use) and, if possible, to recommend further improvements in the methods of employment.

(1) 'The Accuracy of the Modified A.P.I. in the Lancaster.' Bomber Command O.R.S. Report No. B.207. (A.H.B./IIH/241/22/12).

(2) 'The Accuracy of the A.P.I. in the Halifax III. Bomber Command O.R.S. Report No. B.204.

(3) 'The Operational Accuracy of the Air Position Indicator.' Bomber Command O.R.S. Report No. 96. (A.H.B./II/39/1).

As a result of this detailed examination of logs (the results of which were described in a report which was published and circulated by Headquarters No. 4 Group) four faults in the use of the A.P.I. were brought to light and it was shown that their cumulative effect was responsible for mistakes (vector errors exceeding five miles per hour) in 13 per cent of all winds found. The four faults, which were all connected with the re-setting procedure were:-

(a) Re-setting too frequently.
(b) Re-setting inaccurately.
(c) Re-setting to incorrect fixes.
(d) Re-setting without correctly logging the time.

The measure recommended as a partial cure for these errors was that of vector transference in lieu of A.P.I. resets for obtaining 'local winds'. It was suggested that the A.P.I. should be set on leaving base and not re-set again until the target had been reached, unless abnormally strong winds or a very long route made the wind vector of such a length as to become unwieldy. (This method of vector addition or subtraction had been used with considerable success by No. 35 Squadron almost since the introduction of the A.P.I.). This recommendation was among those discussed by the Station Navigation Officers of No. 4 Group at the ensuing meeting at Driffield on 29 May 1943. The problem caused considerable controversy, but the O.R.S. recommendation was finally rejected by the majority on the grounds that the modifications which had been made to the A.P.I. re-setting dials would bring about the desired improvement in accuracy. Nevertheless, two squadrons decided to give the graphical method a trial.

This concludes the general account of O.R.S. investigations into the operational use of the A.P.I.; before leaving this subject, however, mention should be made of two O.R.S. recommendations which, though relevant to this section, have been omitted from preceding paragraphs because of their independence of the particular aspects therein discussed. The first of these recommendations was made verbally to the Air Officer Commanding No.8 Group at the meeting which took place on 12 May 1943 and dealt with the possibility of using the A.P.I. as a blind bombing device, by homing to the estimated air position of the target; a simple method of homing along a line of latitude or longitude was recommended. Although this O.R.S. suggestion was turned down by the Air Officer Commanding on the grounds of restricted tactical freedom it is of interest to note that an almost identical system was later adopted by some Pathfinder Force squadrons for checking H2S blind bombing.

The second recommendation, which was made in the report written at No. 5 Group was for the design and introduction of an 'Air Miles Flown Unit', which would be connected to the flex drive from the A.M.U. and would indicate, by

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direct reading, the number of air miles flown from any desired starting point. It was pointed out that such an instrument should be simple to construct and should improve the accuracy of timing. This recommendation led to the design of the Air Mileage Indicator by the R.A.E. and the results of its service trials, which were all published in November 1944, showed that the instrument functioned perfectly on all test flights giving results which agreed within about one per cent of those obtained from a manual air plot.

The Ground Position Indicator

No analysis was undertaken by the O.R.S. of the operational performance of the Ground Position Indicator (G.P.I.) owing to the limited number of these instruments in service. The part played by the O.R.S. in the service trials of the G.P.I. - H2S combination have been described in the chapter on H2S.(1)

At the request of the Navigation Branch at Headquarters Bomber Command a recommendation was made for the method of use of the G.P.I. against Berlin. The object of this note was to assess the probable accuracy which might be expected from the methods suggested; the estimates of probable error given varied from 1·6 miles for a ten mile run with the G.P.I. to 3·4 miles for a 50 mile run. A modification of this method was later used by the Pathfinder Force with considerable success, though not against Berlin.

Radar Fixing Aids to Navigation

Three radar devices were developed during the war and used as aids to navigation by virtue of their ability to provide accurate fixes under all conditions of visibility. These were Gee, H2S and Loran, and were first used operationally in March 1942, January 1943 and October 1944 respectively.

Gee was originally developed purely as an aid to navigation. However, in view of the difficulty in visual identification of the target much of the O.R.S. work on Gee was devoted to devising ways and means of using it for blind bombing. This work is described in detail in a later chapter where reference will be found to the firing accuracy of Gee and its range and performance over Germany both before and after jamming commenced.(2)

Great interest was shown in the effect of Gee on bomber losses and the O.R.S. carried out a preliminary investigation covering the first two months operations. The missing and crash rates for fitted and unfitted aircraft were compared but it was found that there was no appreciable difference. There was also no indication that the missing rate of Gee aircraft was less than that of other aircraft under bad weather conditions, although smaller proportion of fitted aircraft landed away from base. A second investigation, using data collected over the period March to October 1942, showed that the use of Gee tended to reduce the missing and damage rates of aircraft to which it had been fitted, probably because the aircraft kept more to the bomber stream. The use of Gee, it was also concluded, had appreciably reduced the

(1) See Chap. 12, p. 240.
(2) See Chap. 11, p. 224.

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proportion of aircraft landing away from their own bases on return.[1] ~~(Bomber Command O.R.S. Report No. 74 refers)~~ ~~(1)~~.

H2S presented some special problems as a navigational aid and several analyses were made in attempts to assess its accuracy, reliability and the effect of frequency of fixing on the general navigational performance. In May 1943 (about three months after the first operational use of H2S) an investigation was made into its performance as a navigation aid, the accuracy of fixing being studied in the first place. This work was based on the analysis of a representative sample of navigator's logs to find the position of the aircraft at the time of taking an H2S fix by the methods described above. The results of the analysis ~~were included in Bomber Command O.R.S. Report No. S99,~~ ~~(2)~~ ~~in which it was~~ showed that the method of log analysis was not accurate enough to give more than an upper limit to the errors of H2S fixes if the fix was approximately correct.[2] On the other hand the method did prove that about 20 per cent of fixes were unreliable in that they were subject to very large errors, and it was shown that mis-identification of responses was one of the major causes of this effect. Subsequent analysis on the same lines confirmed this conclusion and ~~in Bomber Command O.R.S. Report No. S.115~~ ~~(3)~~ ~~(which was concerned solely with the navigation problems of H2S)~~ a strong recommendation was made for more careful and continuous dead reckoning (D.R.) plotting.[3] It was argued that the probability of mis-identification was considerable in the absence of an adequate D.R. plot, while a close co-ordination between fixes and D.R. effectively reduced the errors of both to a minimum. The report also showed that individual places varied as regards their reliability as landmarks. Of fixes taken on Antwerp, for example, only one per cent were incorrect against 32 per cent of those of Aachen. In general it could be said that coastal towns were much more easily identified than inland towns while a much higher standard of D.R. was required to identify towns in hilly country or one of a close group of small towns.

Later, Bomber Command O.R.S. Reports Nos. S.155[4] and S.169[5] both based on the analysis of navigator's logs, discussed the effect of the frequency of fixing with H2S on the general navigation performance. They showed that the more frequently fixes were taken the greater the accuracy

(1) 'An Investigation into the Effect of Gee on Casualties,' Bomber Command O.R.S. Report No. 74. (A.H.B./II K/46/48).
(2) 'The Operational Use of H2S, January to May 1943.' Bomber Command O.R.S. Report No. S.99. (A.H.B./II H/241/22/14).
(3) 'The Use of H2S as an Aid to Navigation'. Bomber Command O.R.S. Report No. S.115. (A.H.B./II H/241/22/14).
(4) 'H2S Navigation'. Bomber Command O.R.S. Report No. S.155. (A.H.B./II/69/215 (B)).
(5) 'Performance of Windfinding Aircraft'. Bomber Command O.R.S. Report No. S.169. (A.H.B./II H/241/22/14).

achieved in keeping to planned track and planned time, and the greater the reliability of the fixes. Furthermore, the higher the frequency of fixing the less marked was the variation between individual places of their reliability as landmarks. In short, navigation was most effective when D.R. and fixes were used to their utmost.

In another investigation an endeavour was made to determine the relation between the range at which identifiable responses were received and the height of the aircraft, and in particular how the relation varied with different landmarks. The data was again provided by navigator's logs, but unfortunately it was found that the ranges recorded were not necessarily the maximum obtainable but more probably the most convenient range. For this reason any relation between range and height was masked and could not be measured.

Loran was introduced into Bomber Command as an aid to fixing which would be capable of high accuracy over most of occupied Europe. Service trials of Loran took place in October 1944 when the Bombing Development Unit carried out investigational flights over France; Loran fixes were compared with fixes obtained on the Southern Gee chain and with Mark III H2S. From an O.R.S. analysis of the flights it was deduced that there was no systematic difference between Loran and Southern Gee or H2S. It was discovered that the probable (50 per cent) radial error of a fix was approximately 2·1 miles over France and that the accuracy was substantially constant over the whole of the ~~whole~~ service area.

Loran was fitted to No. 8 Group Mosquito and No. 5 Group Lancaster aircraft which first used the equipment operationally in October 1944. It was suspected at an early stage that the service area was not quite as extensive as had been hoped, and that, due to the distant location of the Rate 5 slave station at Appollonia (North Africa), it was not possible to obtain fixes until fairly deep penetration had been made into Europe. The O.R.S. made an investigation into the results obtained by navigators on three attacks carried out by No. 5 Group, and the poor results in North-west Europe were confirmed. It was considered that more experience and training would help navigators to overcome this difficulty. Nevertheless, it was felt that every effort should be made to improve the performance of the station at Appollonia and if this failed to improve matters then it was recommended that the station should be re-sited. This last recommendation was accepted and the station was transferred to Brindisi (Italy). Unfortunately, it did not become operational until about the end of the European war, but results showed that cover over North-west Europe was improved and there was an area over the southern half of England where S.S. Loran fixes could be obtained.

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The Wind-Broadcasting Scheme

While the introduction of H2S in the spring of 1943 had provided part of the force with a means of obtaining fixes, the accuracy of which was independent of range, the resulting benefits were not shared by all squadrons, many of which had not been equipped by the autumn; moreover, unserviceability of H2S (by no means a negligible factor) reduced its application as a navigational aid. In these circumstances a large number of aircraft were still forced to rely on D.R. for track-keeping beyond Gee coverage. Some assistance was provided by route-markers (dropped by H2S aircraft) but this was limited by weather conditions; moreover, there were reasons for believing that these markers helped the enemy night fighters and increased our losses; they were in fact subsequently abandoned for this reason.

Analyses of navigation on the Nuremburg, Hannover and Kassel raids, made in the autumn of 1943, which have been previously referred to, had clearly shown the degree of scatter liable to occur when the met. winds differed appreciably from those actually encountered (as, for example, on the Hannover attack, 22/23 September). The lack of any uniform system in the choice of winds used by different navigators was also demonstrated.

It was in these circumstances that the wind broadcast scheme was evolved by the Navigation Branch at Headquarters Bomber Command, with the help of the O.R.S. The general intention was that the best navigators in aircraft equipped with H2S and the A.P.I. should find winds for pre-determined sections and height zones of the route, and should transmit these winds to their group headquarters, where the group navigation officer and staff were to work out a mean wind (from the values submitted) which was to be broadcast to the main force. In the early evolution of the scheme only 'past' winds were to be sent out by the groups, i.e. winds referring to sections of the route already covered; these broadcast values were to be used by navigators to correct the D.R. positions which they obtained on these stages; but it was left to the individuals to decide what use was to be made of the winds transmitted for calculating courses for future sections of the route. The broadcasting of 'forecast' winds was not generally instituted until a somewhat later date, though some groups - notably No. 5 Group - were already sending both past and forecast winds in January 1944.

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The general procedure for the transmission of past winds was given in a navigational circular, dated 22 December 1943, and issued by Headquarters Bomber Command. The exact use to be made of these broadcasts was not stated in this directive, which was intended primarily as a 'general introduction' for group headquarter staffs.

The scheme was first tried by No. 4 Group at the end of 1943; the scale of these early experiments was strictly limited, since only about a dozen potential wind-finders were available (six selected crews from Nos. 10 and 102 Squadrons, flying Halifaxes fitted with H2S and the A.P.I.).

The first available results were for the Berlin raid on 29/30 December 1943. Investigation of these figures showed that although H2S unserviceability reduced the number of winds found by the wind-finders and signals troubles slightly reduced their accuracy, the system otherwise worked satisfactorily; the scatter of winds found by the selected navigators was about half that usually obtained from general log analysis. An increase in the number of wind-finders was recommended to offset the reduction due to H2S failures in the number of found winds.

In the three weeks which elapsed between this analysis and the next, the wind-broadcasting scheme was introduced into the whole Command and the transmission of forecast winds was added to that of past values. Wind-finding aircraft were provided by each group, but the task allotted them differed in detail as between No. 5 Group on the one hand and the remaining main force groups on the other. No. 5 Group's wind-finders were to find winds as and when convenient and were to transmit them as found; wind-finding aircraft from the other groups were to find winds at pre-determined heights and times. The two full-scale investigations which were made at this time by O.R.S. officers working in parallel to test the efficiency of the system, undoubtedly unearthed much useful data and enabled valuable recommendations to be put forward. One investigation, carried out at No. 5 Group, dealt with the Brunswick raid on 15/16 January, the report of which, dated 6 February, was circulated by that group. The other analysis, undertaken at Headquarters Bomber Command, was concerned with the attack on Magdeburg on 21/22 January.

Both investigations showed the reluctance on the part of many navigators to use the broadcast winds, and the tendency of many wind-finders to find winds over periods of insufficient duration. Both these faults proved to be extremely difficult to eradicate, despite the intensive O.R.S. and Navigation Branch campaign directed against them for many months. It is evident that long established 'habits' are not susceptible to alteration once a crew has reached the operational phase and it ~~would~~ seemed that the best hope of improvement ~~lies~~ lay with the Operational Training Units. The greater consistency of winds found by crews detailed for this task, which was noticed in No. 4 Group's early experiments, was again apparent from the Magdeburg analysis, though the advantage was less marked.

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This determination, however, disclosed the important fact that the greatest consistency on the Magdeburg raid was obtained by No. 5 Group's wind-finders whose random error was significantly lower than that recorded by the remaining Groups. It was suggested that this was due to the greater tactical freedom given by No. 5 Group to its wind-finding aircraft. Determination of the errors of past and forecast winds showed that while the past winds were considerably more accurate than those normally found by the average navigator, the mean errors of the forecast winds were almost identical with this average. The determinations showed in fact that a slight improvement would have resulted, on this particular occasion, from the use of the past winds as forecast winds, i.e. from sending only one wind value for each stage of the route, this value to be used both for determining the dead reckoning position at the end of the past 'leg' and for calculations of course for the next section.

Errors of the forecast winds were again the main theme of the next O.R.S. analysis of the wind broadcast scheme on this occasion the target was Berlin and the date 24/25 March.[1] The very high winds encountered en route and the large systematic errors of the pre-flight forecast values lent particular interest and importance to this analysis of the results of the wind broadcast scheme which was undertaken on the highest priority at the request of the Air Staff. The results ~~which were published in Bomber Command O.R.S. Report No. S.139,~~ ~~(1)~~ disclosed large systematic errors in the broadcast winds, which were shown to have been caused by two factors:-

(a) Lack of belief in the unusual wind strength by many wind-finders, who transmitted values from five to 15 miles per hour lower than the mean values of the winds which they had found, and omitted to send 50 per cent of their found values

(b) The time-delay between transmissions by the wind-finding aircraft and the reception of these values at Headquarters Bomber Command. An analysis of the use made by the main force of the broadcast winds showed that only slightly more than half the winds used by navigators were the correct values.

The discovery of the time-delay factor was responsible for an immediate improvement which was made to the communication system between groups and command. The misuse of the broadcast winds, however, was not so readily cured; indeed it is doubtful whether any substantial improvement was subsequently achieved, since the next analysis carried out one month later (raid on Dusseldorf - 22/23 April) gave almost precisely the same result.

(1) 'Analysis of Navigation - Berlin, 24/25 March 1944.' Bomber Command O.R.S. Report No. S.139. (A.H.B./IIM/a1/4a, App. O.R.S.).

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This final investigation of the wind-finding and wind-broadcasting series carried out at No. 4 Group in April and May 1944, dealt again with many of the old problems, but included a detailed analysis of errors of calculation and plotting, which had only been fully analysed on one previous occasion for the Magdeburg raid of 21/22 January 1944. The results which were published and circulated by No. 4 Group showed that only 20 per cent of navigators calculated all their winds correctly, i.e. with no errors exceeding five miles per hour. This result was in general agreement with that obtained in the Magdeburg analysis. It was suggested that the accuracy and speed of wind calculations might be improved by giving operational navigators a series of short exercises on the ground, point being awarded for accuracy and speed and inter-squadron competitions being arranged. This suggestion, however, met with little support - the apparent fate of recommendations involving extra work for navigation officers. It was clear that a basic requirement of Operational Training Unit navigation courses was instruction in quick and reliable dead reckoning. In the operational stage the O.R.S. could do no more than indicate those sources of error which analysis showed to exist. Continued practice during the training phase appeared to offer the best chance of improvement.

Miscellaneous Navigational Problems

In addition to the navigational work already described, the O.R.S. was presented, from time to time, with other, incidental problems, the solutions of which are more conveniently considered under separate headings in view of their largely self-contained and disconnected character. The majority were short-term problems which need not be considered here; but five of wider interest and importance deserve reference.

(a) Analysis of the standard of log and chart-keeping.
(b) Method of navigation on a climb.
(c) Route-marking investigations.
(d) System for snap alterations of course to regain track.
(e) Analysis of the accuracy of met. wind forecasts.

(a) Analysis of the Standard of Log and Chart-keeping

A system designed to standardise log and chart-keeping, to ensure that all relevant information was recorded in a manner designed to produce the greatest accuracy, had been introduced by Headquarters Bomber Command in October 1943, together with a standard log and chart. Three months after the introduction of this system an investigation was made to determine the extent to which it was being followed.(1) The operation selected was that against Magdeburg on 21/22 January. ~~and the results were published in Bomber Command O.R.S. Report No. B.201.(1)~~ The report ~~which~~ listed the percentages / of

(1) Note on the Standard of Log and Chart Keeping and Accuracy in Plotting and Calculations. Bomber Command O.R.S. Report No. B.201. (A.H.B./II H/241/22/14).

of the force adhering to each instruction laid down for the standard form of log and chart concluded that, in the majority of cases, there was room for 'very considerable improvement'. The percentage figure for the mean 'percentage adhering' was 47 per cent, and, of the 30 items checked, ten were adhered to by less than 20 per cent of navigators.

A subsidiary analysis showed that the degree of experience of individual navigators did not significantly affect their degree of adherence to the standard log and chart.

(b) Method of Navigation on a Climb

The continuous changes in true air speed which take place in the course of a climb, during which indicated air speed is kept constant, compel the navigator to use some mean value for the height of conversion of indicated to true air speed. The problem which was set to the O.R.S. by the Navigation Branch in June 1943 was to discover whether any fixed ratio could be found between this mean 'conversion height' and the heights obtaining at the beginning and end of the climb; such a connection, if it existed, would allow calculation of the conversion height from the initial and final values - both of which may be assumed to be known.

The progressive steps in the solution of this problem were as follows:-

(a) A height-time graph was plotted for the different types of 'heavy' bomber from rate of climb figures supplies by the M.A.P.

(b) A true air speed-time graph was derived from (a) and a knowledge of the indicated air speed

(c) the mean air distance flown was calculated from measurement of the area under the true air speed time curve.

(d) The mean true air speed was worked out from the mean distance flown and the duration of the climb.

(e) Finally, the mean conversion height was derived from the mean true air speed and the constant indicated air speed.

By application of this method it was shown that the mean conversion height on a continuous climb, at approximately constant indicated air speeds, lies above the initial height at two thirds of the difference between this value and the final height. This discovery, which confirmed that tentatively propounded by the Pathfinder Force - the originators of the suggestion - was published in the Navigational Bulletin and became accepted as standard practice.

(c) Route-marking Investigations

Three route-marker investigations were carried out between the end of 1943 and the spring of 1944. The first was concerned with the accuracy of route-markers in space and time and with their visibility. The raid

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selected for the determination was that against Kassel, on 22/23 October 1943, and the results were published in Appendix A to Bomber Command O.R.S. Report No. 89.(1) The conclusions reached were that, in this instance, firstly, concentration of the force was substantially improved by the route-markers, particularly on the homeward route; secondly, most of the markers were accurately placed, though a few fell ten miles from their intended position towards the beginning of the allotted period, and were backed up by some later markers; thirdly, only about ten per cent of aircraft were too late to make use of the markers; fourthly, in spite of this only slightly more than half the force mentioned having seen them, though this must necessarily be a minimum estimate.

The second investigation concerning route-markers was intended to give a method for obtaining a fix from skymarking flares whose position, at the instant of bursting, could be assumed to be accurately known. The method, which was described in a note dated 20 November 1943, assumed, as stated, a knowledge of the pre-arranged initial position of the skymarker. The only other requirement was for accurate timing from the moment of illumination. No prior knowledge of the wind was needed. So far as is known the method was not used operationally, though this was probably due not to any inherent weakness, but rather to the growing disfavour with which route-markers came to be regarded towards the end of 1943.

The third route-marker problem undertaken in March 1944 was concerned with the best use of these markers. The report ~~(No. S.129)~~(2) aimed at presenting the evidence for and against the use of route-markers, to assist the Air Staff to decide under what conditions they were likely to prove helpful and in what circumstances they might cause higher losses. It was recommended, firstly, that route-markers should be used to concentrate the force after a long sea crossing; secondly, that they should be dropped at as great a distance as possible (30 miles, if possible) from any enemy fighter beacon expected to be used; thirdly, that they should be dropped 20 miles off track on the side where the fighters were expected. The publication of this report was unfortunately rather too late for the adoption of its recommendations, since few long distance targets were attacked for many months after its issue. However, as explained elsewhere, the use of route-markers was discontinued in view of the aid they gave to enemy fighters.

(d) Snap Alterations of Course to Regain Track

In the summer of 1944 the almost complete change from strategic attacks on distant targets to tactical bombing at short range both simplified and modified the navigational problem. The opportunities for obtaining accurate fixes at short intervals over the greater part of the route shifted attention

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(1) 'Analysis of Navigation - Raid on Kassel, 22/23 October 1943.' Bomber Command O.R.S. Report No. 89. (A.H.B./IIK/46/468) or (A.H.B./II/39/1).
(2) 'Note on the Use of Route Markers.' Bomber Command O.R.S. Report No. S.129 (A.H.B./IIH/241/22/14).

from this fixing problem (so pressing on long range operations) to that of accurate timing and track-keeping; thus it introduced a need for a rapid method of calculating 'snap' alterations of course, which navigators could apply in the event of obtaining a fix some distance off the planned track.

This was the problem received from the Air Staff in May 1944. Three rules were formulated on the basis of a drift allowance of from 3^{o} to 7^{o} from the planned track and a true air speed of 200 miles per hour. Each rule gave a course alteration and the time for which the altered course was to be held. The alterations were so calculated that the time (in minutes) bore a simple numerical relationship to the distance off track (in miles). Determination of the errors involved in the use of any of the three rules showed that, for winds up to 120 miles per hour, the percentage errors never exceeded one per cent of the initial distance off track and averaged about one half per cent of this distance. The errors were, in fact, insignificant The accuracy and simplicity of this system gave it a wide application.

(e) Analysis of the Accuracy of Meteorological Wind Forecasts

As a result of a request from the Chief Meteorological Officer, a determination was made by the O.R.S. towards the close of 1943 of the errors of the forecast winds for all operations for which actual winds had been derived. This opportunity was also taken to compare these forecast wind errors with those of the found winds. The results showed that the probable vector error of the met.forecast winds was 13 miles per hour and that the probable error of found winds was 16 miles per hour.

A later investigation (August 1944) was concerned with the accuracy of winds found from balloon ascents. Comparison of the value thus obtained with those derived from Air Position Indicator readings showed a consistent difference of the order of six to ten miles per hour. The available data were too scanty for formal pronouncement, but the results obtained were communicated to Dunstable via the Chief Meteorological Officer at Headquarters Bomber Command.

Training Investigations

The training aspect of navigation was the subject of two O.R.S. reports. The first, ~~Bomber Command O.R.S. Report No. 118,~~ ~~(1)~~ produced at the end of 1944, was on investigation into the standard of navigation achieved at Bomber Command Operational Training Units and Heavy Conversion Units, and paid particular attention to the progress made by navigators passing through these units.[1] It was a very detailed and thorough investigation, during the course of which some 1,700 logs and charts, including ground plots and air exercises, were analysed. In addition, some logs and charts and master plots were examined in order to assess instructors' work.

(1) 'Navigational Training of O.T.U.s and H.C.U.s.' Bomber Command O.R.S. Report No. 118. (A.H.B./IIH/258/3/8).

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The analysis of the pupil's logs and charts was performed to investigate four major aspects of their work, viz: form of log and chart-keeping, accuracy of plotting and calculations, navigational technique and navigation results (timing and track-keeping). Inside these four divisions the analysis was conducted to determine the percentages of navigators attaining an agreed minimum standard in a variety of points covering all aspects of the work.

It was found that at Operational Training Units the navigation improved on all these four points, but on the first Heavy Conversion Unit flights there was a general falling off in standard which was ascribed to the new and faster aircraft, new instruments and the time-lag between the last Operational Training Unit cross-country flight and the first one at the Heavy Conversion Unit. By the end of the Heavy Conversion Unit course the standard of navigation technique results was found generally to be only slightly above that attained at the end of the Operational Training Unit course, whilst the form and accuracy of logs and charts showed improvement.

On the instructors' side it was found that the marking of logs was very haphazard and superficial, and it was strongly recommended that the marking should be systematised. This recommendation was adopted.

The second training investigation, undertaken early in 1945, was concerned with the more general problem of the relation between a navigator's ground and air work.(1) Analysis of logs and charts of a sample of Operational Training Unit navigators was made, the logs being selected so that each navigator was represented by two ground exercises and two air exercises. The analysis was made in respect of the four aspects of navigation that were adopted in the investigation mentioned above, and a rigid system of assessment was developed so that the quality of each navigator's work on the ground and in the air was determined in each of the four major aspects of the work. It was then necessary to find some reliable overall assessment of a navigator that could be applied both to his ground and air work. This was done by maximising the correlation between a combination of technique and accuracy scores and the navigation results scores in respect of air work. These overall assessments in respect of ground and air work were then compared and a fairly close correlation indicated that a navigator's ground work was of approximately the same standard as his air work. It was therefore possible to recommend that a navigator below standard in ground work could justifiably be suspended from air work. ~~(Bomber Command O.R.S. Report No. 128)(1)~~.

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(1) 'The Assessment from a Navigator's Groundwork of his Potentialities in the Air.' Bomber Command O.R.S. Report No. 128. (A.H.B./II/39/1).

CHAPTER 9

TRAINING IN VISUAL TARGET IDENTIFICATION

Introduction

Soon after its establishment the O.R.S. developed a close contact with the Training Branch at Headquarters Bomber Command which led to important work along a number of different lines. This work may be considered under two aspects: firstly, part of it took the form of advice and liaison on training matters, both with the Training Branch and with the units concerned with training. Within this heading is included all the work of development of night vision training, the use of night binoculars and of the analysis and development of training exercises. Secondly, there was the development of certain synthetic training aids, such as a night vision attachment for epidiascopes, lantern slides illustrating methods of target-marking, transparencies for the Air Ministry Bombing Teacher, models to display the development of an attack, and the development of the Cambridge Synthetic Trainer.

It was in connection with advice and assistance which the O.R.S. was asked to give on training matters that contact with the Training Branch first arose. In 1941 and 1942 problems of visual target-identification were most pressing and thus it came about that it was to the training of air-bombers in night vision and the development of Night Vision Schools, that O.R.S. work in this field was first directed. This part of the account is now the most difficult to chronicle since much of the work took the form of personal visits, by the two specialist officers concerned, to Night Vision Schools where the training was effected. Out of such visits there grew many useful but subsidiary lines of work. In 1942 with the introduction of target indicators, interest in night vision training lapsed, but one concrete result of all this early work remains in the Night Vision Training Manual, which was entirely rewritten and redesigned by an officer from the O.R.S.

The analysis and development of training exercises ranks as one of the largest contributions made by the O.R.S. to the improvement of training in Bomber Command. By 1943 there was every reason to think that the infra-red exercise practised by Operational Training Units (O.T.Us) was largely outmoded as a means of assessing target location and accordingly, the O.R.S. developed, in conjunction with the Training Branch, the new 'Flashlight' exercise. The devising of this exercise and the choice of sites in London (the first 'target') for the flashing-lamps used, were almost entirely the work of the O.R.S., and a considerable amount of liaison with the groups was undertaken when the exercise fell entirely upon the O.R.S., and for a considerable period

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provided whole time work for two members of the staff. Two reports were published on this subject, reviewing the progress in target location over a six-months period, by which time the exercise had become a regular part of the Command's training programme. It is not too much to say that the 'Flashlight' exercise permitted an assessment of accuracy in target location on O.T.U. or 'Bullseye' exercises in a comprehensive manner which was a vast improvement upon the standard infra-red exercises in use hitherto. In addition, the use of target indicator candles to mark the target and the effective co-operation of searchlights rendered this exercise as realistic as possible. Again, it was largely due to repeated O.R.S. representations that there was an extensive introduction of target indicator demonstrations on Command 'Bullseyes', a move that more than proved its worth and which was welcomed by all concerned.

In 1944 detailed analysis of operational results, together with scrutiny of practice bombing runs, rendered possible by the night photographs taken on 'Flashlight' exercises, pointed the way to the need for much more practice bombing. The O.R.S. was involved in several ways in the drive for increased bombing accuracy. A considerable work of analysis of practice-returns was undertaken both by group representatives and at Headquarters Bomber Command; much advice and liaison was effected with group bombing leaders, and, lastly, much help was given to the Training Branch in connection with the establishment of the Bomber Command Analysis School. [redacted]

Of the synthetic training-aids developed by the O.R.S. for the Training Branch, the first was the night vision attachment for epidiascopes. It had been pointed out by the Section that the display, at briefing, of target photographs and mosaics by use of an epidiascope often gave crews a very misleading picture of a target as it would appear under operational conditions. This attachment was produced by the General Electric Company with the advice of the O.R.S. and made it possible to display a photograph of a target as it might appear under different conditions of lighting and haze. Considered judgement of the instrument was of the opinion that it was most effective, the only disadvantages being the necessity for a completely darkened room, and the night adaptation required by the audience. An instructional pamphlet on the instrument was written by the O.R.S. and issued as a provisional armament publication.

The introduction of navigational aids and the new techniques of target-marking shifted the emphasis in training from visual identification to practice in recognising and bombing target indicator markers. The introduction of target indicator demonstrations on Operational

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Training Unit exercises were designed to assist pupil crews, but these demonstrations could only be arranged occasionally, and it was not possible to display them to all crews. Accordingly, lantern slides and transparencies for the Air Ministry Bombing Teacher were developed, with the object of displaying to pupil crews different methods of target marking, and of teaching correct points-of-aim. The slides were considered to be useful for briefing and for general instruction, but synthetic training was carried a stage further by the transparencies which provided opportunities for practising estimation of the centres of different target indicator patterns. In the realistic effect conveyed by an image moving across a field of view, the transparencies undoubtedly represented a great advance on the slides, but there are definite limits to the extent to which realism can be achieved by any single picture, and it was to overcome this that the Coningsby Trainer was devised to represent a model raid in progress.

It was considered that by enlisting the co-operation of the Camouflage Directorate of the Ministry of Home Security, a branch that had considerable experience in the production of textured models for viewing under different conditions of lighting, realistic models could be prepared, displaying such features as target indicators, incendiaries, bomb-flames, searchlights, flares and decoys. The electrical work was arranged to be undertaken by the electrical branch at Coningsby base, while it was possible to draw on the experience of the pathfinder squadrons there for advice on target-conditions and for criticism of the different effects. Unfortunately, although the work was completed in some three months, the model was not ready in time for use before the end of the war in Europe. It had, however, a permanent value for training pathfinder aircrew in methods of target-marking.

Early in 1945 it was felt that there was also need for some simple trainer for teaching main force aircrew how to assess the mean points of impact (M.P.I.) of different patterns of target indicators. To meet this need, the O.R.S. turned naturally to the Air Ministry Unit in Applied Psychology at Cambridge, which had already under-taken extensive investigations to determine what were the most difficult factors in estimations of M.P.Is of different patterns. An apparatus that had been constructed by that unit to test pupils' aptitude in M.P.I. estimation, was easily adaptable to form a standard training device. The Training Branch at Headquarters Bomber Command agreed to a contract being placed for 25 of these trainers for use in No. 7 Group as the standard training equipment for assessment of aiming points defined by markers.

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In reviewing all the work undertaken for the Training Branch, one factor stands out clearly, namely the time lag between the need for a particular training aid and the actual provision of that aid. In war-time, the provision of unusual equipment or apparatus even in limited quantities was inevitably subject to production lags. It may be said in retrospect that the production of these training aids was naturally subject to such delays in common with all other equipment, but it is not felt that the work was ever unreasonably handicapped. Thus the introduction of the 'Flashlight' exercise (the provision of the flashing-units making considerable demands on equipment) came at exactly the right time, and proved invaluable for training; the lantern slides and transparencies depicting target-marking also had a long and useful life. In the preliminary work for the provision of the Coningsby and Cambridge trainers valuable lessons were learnt. This apparatus came to hand too late to be used before operations ceased, but with their adoption as standard equipment, they remained to serve the needs of peace-time training.

The Development of Night Vision Training

By the summer of 1942 O.R.S. researches into the problem of visual identification at night had led to the conclusion that navigational aids alone would not bring any great positive advance on bombing technique. The high hopes associated with Gee had not matured and hence there was still much scepticism regarding other radar aids in development, particularly regarding their use and their vulnerability to jamming. Visual identification remained important until radar was to prove its worth. It was clear that something had to be done about the 'human' problem of the air-bomber; this was all discussed in a Bomber Command O.R.S. Report which at that time was in preparation.(1) But the O.R.S. had still no personal outlet to aircrew regarding all it had already learnt on the appearance of the ground at night, on visibility from aircraft and on miscellaneous operational points. Some points were being made in O.R.S. reports but these reports were not at this time fully known to aircrew and often got buried in unit files.

What the O.R.S. needed badly was a shop-window in which aircrew could see its work and which provided a demi-official contact with them. The opportunity was seen when the Air Officer Commanding-in-Chief had asked the Principal Medical Officer to institute, in conjunction with the Training Branch some training in night vision.

This contact with the Training Branch, the second major contact since the inception of the section, was one of those chancy affairs so characteristic of early O.R.S. work. The Training Branch rang up the O.R.S. on the morning of the meeting. This was the first the O.R.S. had /heard

(1) 'A Review of the Problems of Visual Identification of Targets at Night.' Bomber Command O.R.S. Report No. 64. (A.H.B./IIK/10/46B)

heard of the night vision training proposals, and it happened that morning that the two members of the O.R.S. particularly interested in this subject were on duty.

The Inception of Night Vision Training

The O.R.S. represented by Mr. G.W.H. Stevens and Dr. A.F. Munro, offered the Training Branch all assistance, both on the matter of syllabus for instruction, and on the apparatus needed for instruction and demonstration in the new project. The O.R.S. was keen that the operational view-point should be more strongly emphasised than the medical one. Although some difficulty was foreseen in finding an operational man who could appreciate the ophthalmic aspects of the subject the O.R.S. realised that the Command had the right man in Squadron Leader McGown who was then serving as Station Medical Officer at R.A.F. Dishforth. He was an ophthalmic doctor, keen on night vision, and frequently flew on operational flights. His acquaintance was made earlier in connection with the night appearance attachment for the epidiascope. The O.R.S. made a strong representation to both the Training Branch and to Air Commodore Livingstone that Squadron Leader McGown was the man and the O.R.S's representations were successful. An air gunner, Flight Lieutenant Berry, was also posted to Upper Heyford to develop a school for night vision training.

Scope of Night Vision Training

The proposal was to give instruction to air gunners and air bombers in the first place. It was most necessary to avoid the instruction being too concentrated on the medical aspects of night vision, but there was every risk of this happening because the Training Branch was still not very clear on the operational aspects. The opinion of the O.R.S. was more valuable in regard to the operational aspect of target identification at night than it was on methods of recognising other aircraft in darkness. However, many other workers had considered the air to air visibility of aircraft, and the main problem was, in this case, one of collecting and passing on information.

The first school to be formed at R.A.F. Upper Heyford was intended as a school for instructors who would be given information regarding buildings, equipment and material needed to set up a school. They would have a course of practical night vision training which would be rather fuller than they could give themselves on a unit.

The Development of the School of Night Vision Training R.A.F. Upper Heyford

The main part that the O.R.S. played during the development of the school at R.A.F. Upper Heyford would officially be described as liaison. It was mainly a question of making direct contacts in order to get things done quickly. The O.R.S. helped the school in the first place by giving them

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useful personal contacts. There was Mr. Lamplough at R.A.E. and Mr. Nichols of M.A.P. (R.D.Inst.3) who proved valuable contacts respectively on night gunnery training and night binoculars. Mr. Lamplough also helped considerably in the provision of the photometers for measuring night brightness. Possibly the most useful contact was with the Directors of the Camouflage Branch of the Ministry of Home Security at Leamington and in particular, a member of his staff, Mr. B.D.L. Thomas. The Camouflage Branch had prepared a room for viewing models in connection with their work and the technique that they had developed was ideal for night vision training work and in particular for demonstrating some of the features of visual identification of the ground at night. The school at Upper Heyford modelled their demonstration room on the one at Leamington.

The other important piece of equipment was the epidiascope with night appearance attachment. This attachment was by this time fully developed and issued to the service and the school required no introduction.

Filters for the Bombing Teacher

A further point on which the O.R.S. gave advice was the night appearance effect on the bombing teachers. Previously, green and blue filters which were too bright, had been issued for the bombing teacher. Moreoever, the important factor of haze had not been properly considered. It was partly appreciated in connection with the night appearance transparancy of the Ruhr. In this case the reproduction had been blurred slightly and the rivers brightened up. The general effect was more misleading than helpful. The O.R.S. therefore recommended more dense filters and in addition a weak flood of light on the floor to give a haze effect.

One arrangement for producing haze effect which was erected in the bombing teacher made use of a separate light, hung on the ceiling of the teacher, just clear of the aperture through which the picture was projected. The light source was a standard 25 or 40 watt bulb mounted in a square box about the size of a biscuit tin, the lower side of which was one of the blue-green filters already issued to the Service. The lamp had a rheostat connected in the circuit to control its brightness. Some neutral filters out of Service cameras were used to cut down the brightness of the main projection. With this arrangement all the combinations of apparent ground brightness and haze could be reproduced and the result was satisfactory.

Approaches were then made to M.A.P. and to Messrs. Ilford for sets of filters for all bombing teachers. It was suggested that they should be the same size as the transparency, that is about eight inches by ten inches. It was then pointed out that the standard clear neutral emulsions were

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were not manufactured in such large sizes and a silver emulsion was suggested. The fact that silver emulsions scatter light besides absorbing it was acceptable in view of the requirement to simulate haze. Samples were made and it was considered that the amount of light scattered by them provided an adequate haze effect in itself for normal training purposes. The instructors at R.A.F. Upper Heyford felt that there was no need for the independent haze projector and none were made. Neutral filters of density 0.5, 0.75, and 1.00 were demanded but the production was slow. The training staff were anxious that the bombing teachers at all stations were supplied quickly and then the idea was put forward of making the filters from standard service films. A photographic Officer at Upper Heyford experimented with exposure and development and eventually succeeded in producing lengths of film of the required densities.

Manuals for Night Vision Training

Squadron Leader McGown and Flight Lieutenant Berry started the work of producing instructional material before the O.R.S. became involved in this work. The O.R.S. became involved when Air Commodore Linvingstone sent demi-officially to Dr. Munro the draft of the first part of a Night Vision Training Manual prepared by Squadron Leader McGown. This effort was a worthy attempt but Air Commodore Livingstone felt that the text required considerable remoulding and Dr. Munro probably was well suited to attempt this work. This was on 29 March 1943 at which date the Ministry of Home Security's Booklet 'Aerial Observation at Night' had been issued. Consequently Air Commodore Livingstone made the suggestion that the manual should include diagrams in the style of this successful booklet.

The O.R.S. knew of the Ministry of Home Security booklet but had no part in preparing it. Its inception arose at the first meeting of Squadron Leader McGown and Mr. G.D.L. Thomas at Leamington. The latter had already prepared his pictorial booklet illustrating the principle of night camouflage. As this problem was complementary to that of visual identification at night the material could easily be represented to illustrate the other aspect. Thus, with most of the original drawings, revised text, and a few additions, the booklet on 'Aerial Observation at Night' came into being comparatively quickly and was the first publication to get to aircrew.

In view of the fact that 'Aerial Observation at Night' was based on experience of flying over this country at heights below 10,000 feet stress was not made on the correct points and the booklet was, to Bomber Command operational aircrew, rather an academic work. However, nobody denied that it was not a useful work.

After spending a few weeks working on the draft manual prepared by Squadron Leader McGown and generally planning a new manual, the O.R.S. approached the Ministry of Home Security, demi-officially, asking for their

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assistance in the undertaking. This was done on 11 April 1943 when the head of the O.R.S. wrote both to the Head of the Research and Experiments Department of the Ministry of Home Security and to the Director of Camouflage. The chief object was to get the personal assistance of Mr. B.D.L. Thomas who was at that time loaned by the Director of Camouflage to the Research and Experiments Department.

There were further communications from Air Commodore Livingstone on 28 April and 20 May in which he made some suggestions regarding the style of the manual, in particular referring to the Air Ministry Pamphlet on 'Bombing Sense' which made him suggest that the drawings for the manual should be of a humorous character. The O.R.S. did not favour this suggestion, as a sound manual for instructions appeared to be to them the more urgent requirement.

However, Air Commodore Livingstone was not the only person who was making suggestions. News of this project had reached Air Ministry, including the Director General of Medical Services, and The Vision Sub-Committee of the Flying Personnel Research Committee, heard of it and demanded that they should approve it in spite of the fact this was an internal task of Bomber Command. On the other hand, the Director of Camouflage was treating the O.R.S's request for help very enthusiastically and had set up a Night Vision Section. He was, in fact, doing more than was asked of him. In effect, all this enthusiasm and interest was unfortunately providing diversion from the main task and the Training Branch at Bomber Command Headquarters was getting rather concerned. Moreover, the attitude of the Vision Sub-Committee was not well received by O.R.S. who had previously been refused a request to send a representative to the meetings of the Vision Sub-Committee when matters relating to the problem of visual identification at night were discussed. However, it was agreed that the committee should see the manual before it was distributed.

In the attempt to draft the manual in the style of the Ministry of Home Security booklet it was realised that a satisfactory compromise between the requirements of a manual for instructors and one for ordinary aircrew would prove difficult. This matter was causing considerable discussion between the O.R.S. and the Ministry of Home Security and was impeding progress. It was, therefore, decided to take the narrative which was being abridged for the pictorial manual, to finish it as briefly as possible and to add a few sketches and diagrams prepared within the section. This was suggested in a minute to the Training Branch on 23 July 1943, in which the first statement of position had been written down since the O.R.S. had started work on the manual. The suggestion was approved.

The Training Branch issued this document as Part I of the Night Vision Training Manual for Instructors, Part II was a list and description of apparatus and prepared wholly by the Night Vision School. As a

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publication it may not have been well polished but owing to the urgency of the requirement it was accepted as such. It was, however, passed to the more important members of the Vision Sub-Committee before issue for their suggestions.

Having satisfied the immediate requirement, the O.R.S. continued to supervise the production of the manual for trainers. After much delay, due largely to the fact that the Director of Medical Services was producing a booklet on 'Hints on Night Vision', the manual was approved for publication in September 1943. But it was not until twelve months later that it was at last published as Air Ministry Pamphlet No. 162 under the title of 'Night Observation from the Air'.

Visual Identification At Night - Use of Binoculars

Before the O.R.S. was formed in September 1941, the Command's attention had been drawn to the particular value of using binoculars at night. At the levels of brightness occurring at night, the acuity of the eyes is very sensitive both to the brightness of an object and to the contrast between the object and the background; the acuity falls off with the decrease of brightness and with decrease of contrast. Good binoculars which increase the apparent size of the objects without affecting the brightness and contrast, enable more detail to be magnified above the limit of acuity and blurred patches become definite shapes. Thus the use of binoculars for peering at the ground from an aircraft offered definite hope of benefit.

The Ministry of Aircraft Production arranged for a number of pairs of binoculars to be issued to operational aircrews together with a questionnaire regarding the operational value of binoculars. The trials were somewhat mishandled for neither were the binoculars issued in good condition, nor were the crews instructed in the art of using them. Moreover, the questionnaire was not very good and some contradictory and not very helpful reports were obtained.

It was at this stage that the O.R.S. picked up the threads of the problem and the use of binoculars was made the subject of a conference between the Air Staff, Headquarters Bomber Command, O.R.S., M.A.P. and R.A.E. representatives. Moreover, it was discussed with Sir Henry Tizard at a conference on the general subject of target location by night. It was generally agreed that the value of binoculars had not been proved and that new, well-organised trials should take place. A member of the O.R.S. should watch carefully over them and a member of R.A.E. should visit the stations and instruct the observers on points on their use. This was essential in view of the experience of their use discussed in R.A.E. Department Note No. Inst. 460.

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Even if binoculars were useful the supply position at the beginning of 1942 was acute. The limited available supply was reserved mostly for Coastal Command. With difficulty, six pairs of Ross 4 x 25 mm and six pairs of Barr and Stroud 7 x 50 mm binoculars were made available for these trials and issued to two Bomber Command squadrons, Nos. 97 and 78. Appreciating the supply difficulty, the Director of Operational Requirements had been obliged to place a development contract for binoculars prior to these trials and, on the experience of the flights made by R.A.E and on the work of O.R.S. Coastal Command, had decided to ask for a five times magnification. Whatever the outcome of the trials binoculars of five times magnification would be required. The main point was, therefore, to discover whether binoculars could be applied at all to the night bombing problems.

In the trials several experienced air observers were selected and each was specially instructed in the use of binoculars at night, particularly at focusing and on the difficult point of setting the eye separation, which was checked and then fixed by the R.A.E. representative

Reports on the value of binoculars were varied. It must however be admitted that some users were irrationally prejudiced against, or enthusiastic for binoculars and the amount of use being made was barely enough to prevent results being outweighed by such considerations. In addition, one had to risk aircrew members attempting to use binoculars under conditions in which they would be of no use at all, such as dark, hazy nights; the frequency of such occasion was quite high. One could generally see something unaided and not just blackness under conditions where binoculars revealed more detail. This something was claimed to be just enough to map-read at night and the main point was the extent over which one needed to see to map read, this being considerably larger than the field of view of even the best binoculars. Some users claimed that binoculars were of value in examining fires to verify if they were real or decoy, in or out of built-up areas. The general opinion however was rather unfavourable since binoculars on the whole gave very little help in map-reading at night.

It should be remembered that the above trials took place previous to the introduction of marking techniques.

A revival of interest, in spite of the conclusions of the trials, came as the result of the introduction of night vision training in the Command. The medical officer, then Squadron Leader McGown, attached to the central school was an opthalmic specialist and a keen advocate of the use of binoculars. It was, therefore, decided to include in the course, training in the use of binoculars at night and encourage those

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who were keen to try them on operations. The section helped the school in getting viewing-room demonstrations for binocular training organised.

The next stage came with the introduction of marking techniques, and No. 8 (Pathfinder Force) Group was formed. It was clear that if binoculars were to be of use to anyone it would be the pathfinders. Squadron Leader McGown went to the Pathfinder Force as Group Medical Officer and was in a particularly strong position to advise the operational crews on using binoculars for their new tasks. In the circumstances the O.R.S. felt that the operational problem would soon be considered as well as it could be and ceased taking an active part in any further developments. The section, however, reviewed the position on the use of binoculars in a review on the problem of visual identification.(1)

General Training in Target Identification

When it was fully realised in 1941 that the chief reason then for the ineffectiveness of many bombing missions was the failure to identify the target by night, a very broad survey was needed of the new problem of increasing our success. As not even the Air Staff had then much experience of the problem, all possible lines of improvement were examined Although the most hopeful solution lay in the new bombing and navigational devices that were then under development, the question of making better use of the means already available was carefully considered. This covered the general training in target location and, later, target marking techniques.

At the beginning of 1942 there was only one way of identifying a target and that was visually. Owing to the fact that weather conditions often prevented visual identification, bombing was done on dead reckoning. The latter procedure was, however, not regarded as a method of identification and is considered in the chapter on navigation.(2)

Infra Red Target Location

The first contact with the Training Branch at Bomber Command came at a meeting to discuss night glasses. A member of the Branch suggested afterwards that something might be learnt about target location and the use of night glasses by an examination of the success with which Operational Training Unit crews located 'infra-red' targets.(3)

(1) 'A Review of the Problems of Visual Identification of Targets at Night.' Bomber Command O.R.S. Report No. 64. (A.H.B./II K/46/46 B).
(2) See Chapter 8.

(3) On navigational exercises by night O.T.U. crews were briefed to attack certain targets (docks, factories etc.) where an 'infra-red' lamp was situated which flashed a trace on 'infra-red' film.

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Out of this suggestion, action was taken in February 1942 to obtain a return from the O.T.U's giving particulars of attacks on 'infra-red' targets.(1) Success was analysed according to height of attack, weather and target, and the results were made the subject of a Bomber Command O.R.S. Report.(2)

Target location on O.T.U. exercises was in no way comparable with that on operations for there were important differences in the conditions under which the tasks were carried out. In 1942 Bomber Command training was still under the restrictions imposed during the Blitz in that training flights had to be made below a ceiling of 7,000 feet whereas operational heights were greater than this and there is a big difference between what can be seen at night from 5,000 feet and from 15,000 feet. Moreover, there were none of the visual distractions such as searchlights, flak, fires (real and decoy) so that it was not surprising to find that the standard of target location on training flights was moderately satisfactory.

As attacks by the G.A.F. on this country had abated a recommendation was made to the Air Staff that some action should be taken to get the height restrictions on training released and have training exercises taking place at operational heights. It was considered most undesirable that crews should fly high for the first time on operations. It had also been suggested, not only by the O.R.S., that there should be some co-operation between Fighter Command, A.A. Command, and Bomber Command with the view to staging an exercise in which the home defence practised with O.T.U. crews. It was late in 1942 that an inter-Command collaboration to institute Bullseye exercises took place, but the O.R.S. had turned away from these training exercises because of other urgent problems.

The Early Bullseye Exercises

In March 1943 the O.R.S. re-examined what was happening on the 'Infra-Red' and Bullseye exercise in the matter of target location. The first Bullseye exercises had been inaugerated mainly for the purpose of fighter and searchlight affiliation but later an infra-red lamp was placed at Westminster Bridge which was briefed as the aiming point for exercises over London. Three exercises, which took place in August 1942, were examined and it was discovered that only a small proportion of these crews claiming to bomb the target did, in fact, show a trace of the infra-red lamp on their photograph. From the coverage of the camera this meant that unsuccessful crews were at least a mile away but, even in March 1943, to be within a mile of the aiming point on operations

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(1) Bomber Cmd File B.C./S.26383.
(2) 'Analysis of O.T.U. Exercises.' Bomber Command O.R.S. Report No.B.115

still considered a creditable effort.

It was clear that these Bullseye exercises were proving of great value and were producing results on target location more like those achieved on operations. The information which had previously been obtained from ordinary infra-red exercises was superceded; an investigation of them therefore ceased and the returns dropped.

Apart from any value attached to the results of target location on Bullseye exercises as such, a point which struck the O.R.S. was the unsatisfactory nature of an exercise in which the majority failed to reach the target and the evidence was presented in a negative form. It was vital to get positive evidence about a larger proportion of the unsuccessful. In operations, by using night photography, the O.R.S. generally knew where the unsuccessful crews strayed but in training it could not use this technique owing to the dangerous nature of falling photo-flashes. A memorandum was written making suggestions for improving the records regarding the whereabouts of crews at bombing. This memorandum was passed to Air Staff Training Branch [1] but not published. In it, the possibility was considered of placing an array of infra-red lamps around the aiming point, each lamp coded, so that a plot of the near misses could be obtained. However, the supply of these lamps was small and further production was out of the question. Consequently the point was made that, since the main force now bombed visible markers dropped by the Pathfinder Force, the use of a light as an aiming point and a number of visible flashing lights placed around for the purpose of plotting near-misses should be acceptable. Moreover, crews had no longer to search for the target by what they could see of the ground. These points were taken up by the training branch and the Flashlight exercise was conceived.

The Flashlight Exercise

On an unofficial arrangement, without reference to Air Ministry, the Training Branch with the assistance of O.R.S. carried out an ad-hoc experimental investigation to find a suitable form of target layout, employing visible lights. The first Flashlight layout was erected in London, placing the units on the balloon sites. The layout was surveyed and mapped by the O.R.S. for the maiden exercise on the evening of 15 September 1943.

Further exercises were withheld until O.R.S. analysed the first exercise, partly to get the necessary experience of practical snags before preparing instructions on plotting for units. Two reports were published, one giving the general results of the exercise [2] and the other a description of the system of lights and the method of plotting points of aim. [3] Previous to the publication of the reports a lecture was given by

(1) Bomber Cmd. File B.C./S.26383, Encl. 33 A.

(2) 'Report on Exercise Flashlight, 15 September 1943.' Bomber Command O.R.S. Report No. S.108. (A.H.B./IIH/241/22/14).

(3) 'Flashlight Exercises - Description and Method of Assessment of Bomb-Aiming Accuracy.' Bomber Command O.R.S. Report No. 79. (A.H.B./II/39/1).

by a member of the O.R.S. to an assembly of group bombing leaders and group photographic officers at Bomber Command Headquarters in which the Flashlight exercise was fully explained together with an account of the method of plotting. Written instructions were issued following this lecture and group bombing leaders were made responsible for instructing their unit bombing leaders before the exercise restarted.

The exercise gave a plot of photographs very similar to an operational plot, rather better perhaps, but it showed crews bombing over two or three miles away from the target. Moreover, a large proportion failed to reach the London area at all, the films showing no light traces and many were reported to be taken over 10/10th cloud. (There was no cloud over London during the exercise). These failures led the O.R.S. to ask Fighter Command to provide a plot of the Royal Observer Corps tracks for that night to see what information had been given. Although it was not complete it did show a number of tracks missing the centre of London by many miles and it was this Royal Observer Corps plot, with its other revealing features, which started the investigation into 'Bullseye' navigation described in Chapter 8.[1]

Arrangements were made for the O.R.S. to receive the Flashlight plottings made at the units partly to discover what further snags were arising and what mistakes were most frequent. There were a few exercises in October but then there was an interruption for two months and the O.R.S. eventually analysed the exercise of the period from December 1943 to March 1944. The resulting report[2] was an analysis of the mistakes made in interpretation and plotting; it gave, as an appendix, a number of hints in plotting which had arisen out of O.R.S. experience of plotting. The concentration of the photo-plots on these exercises had improved somewhat and in the case of the targets at Newcastle, which had very few searchlights, was showing sufficiently good results that the errors in the method of calculating bomb strike from the photographs were becoming an appreciable part of the total error.

After March 1944, the O.R.S. continued to receive results of Flashlight exercises and provide the Training Branch periodically with information of the accuracy and effort being achieved. In many groups accuracy appeared to be deteriorating and, as by this time bombing operations required more precise bombing and a great drive had been made in bombing accuracy, it was felt that the cause was the failure to understand the plotting method, as a result of many changes in the unit personnel since the original instruction was given, the O.R.S. had not had time to check any more of the plots by unit bombing leaders but supported this feeling and consequently instruction on plotting was included as a regular part of the syllabus of the Bomber Command Bombing Analysis School.

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(1) Bomber Command File B.C./S.26484/4.

(2) 'Analysis of Flashlight Exercises, December 1943 to March 1944.' Bomber Command O.R.S. Report No. S.149. (A.H.B./II/M/a1/4a, App.O.R.S.).

The question of fundamental plotting accuracy was raised in Bomber Command O.R.S. Report No. S.149 and was further raised by the Scientific Adviser to the Air Ministry who thought that the errors were more serious than the O.R.S. had estimated. Moveover, at the same time, the O.R.S. was questioned by the Training Branch on the accuracy of simulation of bombing by day. There did not seem to be much difference in these two problems. An examination of both flashlight film and the line-overlaps of day simulation bombing were made to determine the errors due to unsteadiness of the aircraft displacing the camera axis from the vertical. It was estimated roughly that the average error of estimating bomb point when flying at 10,000 feet was a little under 200 yards, and would increase with height proportional to the 3/2 power of height. However, the O.R.S. was not satisfied with this quick answer and proceeded to examine more closely the theory of the errors of plotting and to relate these errors more closely to the deviation in the light track obtained on the film. Mainly due to more important jobs this investigation was not completed.

During the first six months of the Flashlight exercise the O.R.S. made several recommendations for improving the exercises. First of all, the aiming point consisted of three red searchlights pointing vertically and it was suggested that a pyrotechnic target would be more effective in which actual target indicator candles were burnt on the ground. These suggestions were adopted and proved very effective. A further point was on the siting of the letters. It was found to be very tricky to assess the beginning or end of a trace of a flashing letter having a brief flash such as 'A' or 'T'. In London the codes were allocated at random and such letters as 'A' and 'M' occurred at vital positions. When preparing the layout for the Bristol and Newcastle targets the long morse letters e.g. 'J', 'Y', 'Q', 'C' and 'X' were placed at about the release range from the target in order to have a long flash on those traces which were most likely to be used.

Use of Flashlight targets to analyse Bombing Runs

There is no doubt that Flashlight exercise helped in sorting out some of the gross errors on the Heavy Conversion Unit and Operational Training Unit bombing exercises and No. 91 Group, in particular, were getting extremely good results. Target-location and bomb aiming had so much improved by the summer of 1944 that photographic methods for simulating bomb aiming were losing their value owing to the inherent inaccuracies of the system. However, it was realised even at the time of writing Bomber Command O.R.S. Report No. S.108 (1) that the flashlight system could give much information on how the aircraft was flown. It had become surprisingly apparent during the raids on the Marshalling Yards in France, which were contemporary, that the flying side was responsible for much of the error in bombing.

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(1) A.H.B./II H/241/22/14.

It was quite clear that, in order to improve our bombing, we did not just need to know the errors of bombing but what caused them. It was with this point in mind that the recommendation was made in Bomber Command O.R.S. Report No. 149 (1) to modify the use of the camera so that more record was obtained on the run up, the track of the camera axis and aircraft heading being plotted from which the track and the maneouvres of the aircraft could be deduced. This recommendation was tried out in two Operational Training Units of No. 91 Group and some interesting records obtained. A note was written on three of them, describing the results and demonstrating the potentialities of the scheme and submitted to the Training Branch.(2) Unfortunately this line of attack came to a dead end since the organisation of Flashlight exercises was then in difficulty. This prevented action and finally the proposal had to be shelved. However, it was considered something that should be held in mind for future training.

Night Appearance Attachment for Epidiascopes

In the first few months of the O.R.S. being formed, investigations were already in hand to discover methods by which help could be given to operational aircrew in their problem of visual identification of the ground at night. The O.R.S. learned that the Research Laboratories of the General Electric Company (G.E.C.), Wembley, had simulated the appearance of the ground at night in the laboratory. A visit was therefore arranged to the G.E.C. by representatives of the O.R.S. and of Bomber Command Air Staff to see this simulation.

The arrangement was a double projection lantern in which one half of the projection was a vertical air-view of the ground, cut down in intensity so that its brightness appeared as the ground would appear at night. The other half of the projection was used to superimpose the ground reflection of a system of artificial lighting (e.g. street lighting). It also provided the haze due to the scattered light in the atmosphere.

It was suggested at the meeting that the principles of the simulation could be effected on the epidiascope and if this could be easily done, then it would be a good idea for the intelligence officers at briefing to show aircrews just how the target was likely to appear that night. This suggestion was accepted although it was pointed out that there were practical difficulties in using the epidiascope in this way at normal briefing. For instance, the room had to be darkened and aircrew had to be dark-adapted. Better use should be possible at the specialist briefing of navigator-observers.

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(1) Air Ministry Science 1 Library.
(2) Bomber Command File B.C./S.31640.

The G.E.C. were authorised to make an experimental model and in the meantime the O.R.S. would arrange for some slides made from reconnaissance photographs of some German targets and some corresponding enlargements. The former were for showing on the G.E.C. lantern and the latter on the epidiascope. When the attachment was made a further meeting at G.E.C. was to be arranged to consider this attachment.

At the second visit to the G.E.C. Squadron Leader McGown joined the party. As already noted he was then Senior Medical Officer at Dishforth and was a keen man fully aware of the night vision problem then confronting Bomber Command. The demonstration was very successful and the attachment was given to Squadron Leader McGown to try out at Dishforth.

A second attachment was made which a member of the O.R.S. took around some stations in No. 3 Group. Here some mixed opinions were encountered, some squadrons being keen, and others saying that its value would be more appreciated at the Operational Training Unit. However, from these visits, many of the difficulties of using it on stations revealed themselves. In many cases, it was difficult to find a suitable room which could be made light-proof and the range of photographs and mosaics at a station was limited, many being useless for this particular purpose.

It was clear that the attachment was going to be of limited value, but it was agreed to put forward an operational requirement for it since it was simple and most units had already epidiascopes. In the meantime, whilst it was being manufactured, the O.R.S. was to look into the provision of more suitable photographs.

The investigation which the O.R.S. did to find photographs suitable for simulating night appearance was written up in a Bomber Command O.R.S. Report in which reasons were given why the existing photographic mosaics were unsuitable and recommendations were made for the future.(1)

It is, however, important to record that by the time the above report was drafted, Night Vision Training was being organised, and the night appearance attachment was obviously a useful piece of ancillary equipment for Night Vision Training centres. The emphasis was therefore changed from operational to training particularly since suitable photographs of operational targets were likely to be unobtainable and, secondly, since the importance of visual identification by natural night light was rapidly disappearing from the operational task.

From the training point of view photographs taken in this country at specific conditions, some high, some low and over-cast, would be the most useful and arrangements were made to obtain them. They would provide a comparative set for projecting the appearance of the ground at night under a high moon, low moon or starlight. The Night Vision School at Upper Heyford chose Oxford, Northampton and Kings Lynn as suitable

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(1) 'Photographs for use with the Night Appearance Attachment for Epidiascope'. Bomber Command O.R.S. Report No. 70. (A.H.B./II/39/1)

subjects, and line overlaps of photographs were taken of each place, starting from a prominent landmark about ten miles from the town and extending to a point a mile or so beyond the centre of the town. The O.R.S. supervised this photography at R.A.F. Bicester.

When about five overlaps were obtained, they were passed to the Night Vision School who were rather disappointed with the results. Great care had been taken in the photographs and a considerable amount of preliminary work done to ensure that the range of contrast on the photographs was approximately that as seen by the eye at night. The flatness of the photographs was probably correct but it was discouraging after using the rather highly contrasted reconnaissance photographs.

The future success of this work was, therefore, subject to doubt and, in view of the great decline in the importance of visual identification at night by natural light, it was dropped.

Production of Lantern Slides Illustrating Target-Marking at Night

It was the practice in 1942 to include in night sortie raid returns, details of how individual aircraft identified their targets. This information was provided in answer to the specific questions, which were asked at interrogation. 'Explain how the target was identified?' and 'was the target seen in the bombsight?' (1) With the introduction of target indicator marking in 1943, individual aircraft of the main force no longer attempted to identify targets visually but aimed their loads at markers dropped by a pathfinder force. The interrogation pro forma was accordingly amended to include the questions 'What did you aim at?' and 'Were any markers seen to cascade?' (2)

Later instructions issued the same year laid down that 'it should be stated if the target was identified visually or on special equipment, or by target indictors seen on the ground or cascading' and introduced the questions 'What was in your bombsight?' and 'How did you identify the target?' to which such answers were expected as 'By red target indicator markers' or 'by centre of concentration of red and green target indicators seen on the ground.' (3) These questions reflect the increasing importance attached to the recognition and bombing of target indicator markers, whereas previously much dependence had been placed upon the identification of ground detail. This change in the methods of bombing brought with it

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(1) Bomber Command File B.C./S.25337/I, Encl. 14B.
(2) Bomber Command File B.C./S.25337/I, Encl. 46B.
(3) Bomber Command File B.C./S.25337/I, Encls. 50A and 55A.

a number of new problems. There was need to train air-crews in the recognition of target indicator markers, both by providing opportunities for target indicators to be seen burning under practice conditions, and by the production of slides and drawings showing typical methods of target marking. The production of descriptions and illustrations of target-marking is considered here, while the provision of target indicator demonstrations is treated elsewhere.

An O.R.S. note of May 1943 on training in recognition of target indicator markers (1) proposed as possible methods of producing suitable descriptions of markers, the production of:-

(a) Still photographs and slides showing target indicators as seen from the air,

(b) Paintings and drawings which might portray a target as seen by an air-bomber,

(c) Cine photographs of markers from both air and ground.

It was thought that (a) might be quickest since photographs might already exist at the Central Interpretation Unit from which coloured mosaics could be made. As regards (b) it was proposed that an artist from the Camouflage Branch of the Ministry of Home Security at Leamington Spa, with which ~~the section~~ the O.R.S. had already been in touch over other work, should be given facilities to fly on some target indicator demonstrations that he might produce paintings of target indicators and schematic drawings showing markers at various stages of burning. Proposal (c) led firstly to the suggestion that ciné films be produced by the Film ~~Processing~~ Production Unit, and later, to the assembly of the best sections of all such films into one annotated picture for training purposes. Air Staff approval was given to these suggestions.

Work on these problems was carried on in June and July and the position was reviewed at the beginning of August.(2) By then, a coloured cine film had been prepared but was not regarded as satisfactory. Some rough sketches had been produced by the Camouflage Branch, after two of their officers had been given an opportunity to view a number of target indicator demonstrations. Experiments were in hand to reproduce these pictures as lantern slides. The review of the position made it clear that it was now fully appreciated that bombing on target markers was far more satisfactory than for aircraft to locate their targets independently, without such aid. At the same time, from the aspect of training, this new technique brought its own problems. It was strongly felt that crews needed to be trained in the recognition and bombing of target indicator markers. The distracting effects of other light sources were appreciated,

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(1) Bomber Command File B.C./S.29561, Encl. 17A.
(2) Bomber Command File B.C./S.29561, Encl. 24A.

as also the need for training of air bombers to study these effects. As well as lantern slides and posters it was proposed to the Training Branch that to meet these needs there should be more frequent and elaborate target indicator demonstrations, and that the Air Ministry Bombing Teacher should be adapted to display target indicators and searchlights, special transparencies being made. Both these suggestions developed into full scale commitments which are described in the appropriate sections of this chapter.

Instruction by means of lantern slides and posters was judged to be most valuable since a large audience could be instructed at a time, whereas there had inevitably to be a long delay before all Operational Training Unit air bombers could see a target indicator demonstration, at the rate at which these were being held. It was considered most important to give an accurate rendering of colour and glow, and to introduce a realistic effect of distracting fires, incendiaries and lights in the background. It was decided that the slides should depict some of the standard types of markers as they might be seen by main force crews under operational conditions.

In the early attempts at slides, considerable criticism was raised on a number of points, such as the rendering of target indicators and fires, unsuitability of view, absence of scale, and the like, and it was not until early October 1943, that three slides were produced, which were acceptable in a general way to the Air Staff at Headquarters Bomber Command and which met the criticisms offered by operational aircrew. Close liaison was maintained over the production for the next month and the Camouflage Branch were supplied with Central Interpretational Unit operational plots of target indicators and with mosaics representing a target at night, prepared from night photographs.

In a conference at Leamington in the middle of November (1) the Camouflage Branch undertook to complete within a week five prototype slides meeting previous criticisms. The operations to be represented were vertical views of three stages, early, middle and late, in the development of a Newhaven attack, and of intermediate stages of Oboe ground marking and of H2S blind marking. The Camouflage Branch would then produce 40 sets of the first issue of slides within ten days, as production was by now regarded as most urgent. The Director also agreed to the Branch retaining a research commitment to experiment in the production of improved slides, with better rendering of glow, haze and background.

One more display of the trial slides was given at Headquarters Bomber Command to meet further criticisms and the five slides were then agreed upon. In considering in retrospect the long time taken in production it must be realised that this period was one in which methods of target marking were undergoing rapid development, and that opinions of operational aircrew on the appearance of a target were widely divergent /according

(1) Bomber Command File B.C./S.29561, Memo. 38.

according to their personal experience. It was thus very difficult to produce pictures that would meet all comments and serve as a basis for general agreement. The criticisms most frequently made related to the arrangement and spacing of the various lights (target indicators, fires, incendiaries and flares) represented, and to their colour and the presentation of haze and smoke. The scatter of the target indicators depicted, was considerably criticised in some quarters, though the patterns of both target indicators and fires were in fact adapted from actual Central Interpretation Unit operational plots, which were chosen from a number of examples as typical patterns.

A full description of the method of production was prepared and should be consulted for details,[1] but briefly the pattern of a carpet of lights across a target, recorded on the night mosaics, was copied as a series of pin-pricks in black paper. The paper was illuminated from behind, and photographed through glass to introduce the appearance of haze and glow. The photographs were reduced to lantern slide size and each slide was hand-coloured. Only by photographing a direct light source, such as light showing through pin-holes in paper, could the necessary contrast be obtained between the intense brightness of target indicators and incendiaries and the surrounding blackness. The colouring of the target indicators raised further problems since the markers were the brightest light-source present, and introduction of colour cut out some of the light. A compromise had to be made with use of rather thin colours.

The first issue of 40 sets of five slides each, was finally despatched to Operational Training Units and Heavy Conversion Units towards the end of December 1942. Two short notes,[2] the first describing the slides, drawing attention to the salient features in each method of marking, and indicating the aiming point on each example, and the second containing instructions for showing the slides, were prepared by the O.R.S. and circulated by the Training Branch. The slides were to be held by Unit Bombing Leaders. A month later 45 more sets of slides were ordered by the Training Branch to meet requests from Operational Training Units and Operational Stations, and attention was drawn to the existence of these slides in the O.R.S. report on methods of target marking.[3]

About this time when different methods of target marking were becoming well established it was realised that it was not sufficient to instruct air bombers to aim at the centre of a pattern of markers, but that training and experience were necessary for such a choice to be made correctly. In regard to the slides already issued it was felt that there should be no discrepancy in instruction in this essential aspect

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(1) Bomber Command File B.C./S.30893, Encl. 113A.
(2) Bomber Command File B.C./S.29561, Encls. 42B and 42C.
(3) Bomber Command File B.C./S.29561, Encl. 49B.

of the choice of the correct visual Mean Point of Impact of a group of markers. Accordingly keys to the slides were issued in the form of coloured drawings on which the M.P.I. was indicated by a Mark XIV bomb-sight graticule superimposed in the correct position for bomb release. The visual M.P.I. was the same as the mathematical M.P.I. except in cases where outlying isolated markers were ignored. Unit bombing leaders were instructed to arrange for pupil crews to practice in picking out the M.P.I. of each slide, and then to check and correct their results with the aid of the keys now issued.(1)

The Camouflage Branch continued their experiments on the production of slides giving a more realistic picture of a target area and the O.R.S. maintained a continual liaison with the Branch in connection with this work. In the meanwhile, however, decisions had been reached by Air Staff (Training), on the production both of a training film on bombing tactics, which was to include a section on target marking, and of transparencies for the Air Ministry Bombing Teacher, representing a target under attack. In view of these new training aids, the production of further lantern slides was withheld, but much of the experimental work undertaken to produce more realistic slides proved invaluable when six months later the preparation of transparencies for the Bombing Teacher was begun.

In retrospect it may be said that at the time of issue these slides served a valuable purpose, and were used for training and for briefing at O.T.Us and operational stations. They became out of date, as methods of target marking changed and the accuracy of marking increased, and were eventually replaced as a training aid by the Air Ministry Bombing Teacher transparencies. The slides suffered from the inherent defects that each represented a single vertical view, and that the picture was static and not the aspect that an air bomber would see at bomb-release. Again, the slides were viewed on a vertical screen and for proper presentation a completely blacked-out room, in which pupils could acquire night adaptation, and a projector emitting no extraneous light were necessary. These conditions were not always attainable at stations. Such defects were overcome by use of transparencies in the Air Ministry Bombing Teacher described in the following section, and had it not been for the preparation of these lantern slides, work on the transparencies would never have been so far advanced.

Preparation of Air Ministry Bombing Teacher Transparencies Representing Target Conditions and Target Marking

Problems of target identification were continually under consideration by the O.R.S. and soon after the section was formed, in 1941, joint meetings were held with the Air Staff to discuss identification

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(1) Bomber Command File B.C./S.29561, Encls. 42B and 42C.

of targets. This early work was reviewed ~~in Bomber Command O.R.S. (1)~~ and ~~Report No. 64 in which~~ a few paragraphs were devoted to training aspects.[1] In discussing the Air Ministry Bombing Teacher, the opinion was advanced that insufficient use was being made of the potentialities of this instrument. The bombing teacher had the great advantage over an epidiascope in that viewing it from the vertical in a bombing compartment with a restricted field, and with flak and searchlight simulation to give a fairly realistic effect of actual operational conditions. The addition of haze and illumination control made the instrument of great value for training purposes, provided a proper technique for its use in teaching were worked out. Although the O.R.S. maintained interest in the Air Ministry Bombing Teacher it was in connection with the development of night vision training that the use of the instrument was first developed.

The question of the preparation of transparencies for the bombing teacher from night photographs of actual target areas together with coloured transparencies, was raised in August 1943 [2] but at that time work was concentrated on producing lantern slides. The slides were simpler and quicker to make than transparencies and when a year later the production of transparencies became a definite commitment, it was found that many of the difficulties associated with their preparation had already been solved in making the slides.

The need for more extensive training in recognition of target indicators and estimation of the centre of a pattern of markers was raised in May 1944 by the publication of a Bomber Command O.R.S. Report ~~No. 99 (3)~~ on the visibility and recognition of target indicators.[3] In this report the view was advanced that training in recognition of target indicators should be a fundamental part of an air bomber's training, but that in spite of its importance little had so far been done. Demonstration of target indicators on Bullseye exercises had been arranged, but by no means all Operational Training Unit crews had seen these. Coloured lantern slides were available for instructing crews in the appearance of target indicators in relation to a target area. These slides were of value for training, but did not represent all the difficulties, and further research into methods of synthetic training was required. Already the Directorate of Camouflage had been asked by the O.R.S. to experiment on means of simulating target indicator markers, flares, fires etc. on the standard bombing teacher.

By the end of June experiments had been carried sufficiently far to show that a realistic simulation could be achieved, and the Training Branch requested the production of 160 transparencies. A meeting was held at the Directorate of Camouflage on 26 June to discuss their production. It was apparent that the rendering of incendiaries, fires and glow was a great improvement over earlier techniques used in making

(1) 'A Review of the Problems of Visual Identification of Targets at Night'. Bomber Command O.R.S. Report No. 64. (A.H.B./IIK/46/46B).
(2) Bomber Command File B.C./S.28854, Encl. 86A.
(3) 'The Visibility and Recognition of Target Indicators.' Bomber Command O.R.S. Report No. 90. (A.H.B./II/70/1)

lantern slides. It was agreed that the O.R.S. should provide both photographs representing target conditions at night and operational plots of target indicators prepared by the Allied Central Interpretation Unit and representative of different methods of marking. The O.R.S. also undertook to advise on such points as target conditions, colour of target indicators and other problems as they arose in the course of production. In view of the work which was being done by the Air Ministry Unit in Applied Psychology at Cambridge on the production of instruments for training air bombers in aiming at the centre of a group of coloured markers, as will be seen in the following section, the Camouflage Branch undertook as a further commitment the preparation of transparencies for use in the Cambridge Trainer. The Air Ministry Unit in Applied Psychology in their turn were to review the target indicator patterns supplied by the O.R.S. in order that they might select patterns which their experience showed either to present difficulties to air bombers, or to provide maximum training value. (1)

By August a number of prototypes transparencies had been produced and had been circulated to O.T.Us. In the light of the favourable comments expressed on their value as a training aid, the Training Branch altered their previous order to 170 sets of two transparencies, enough for one set for each Air Ministry Bombing Teacher throughout the Command. Each transparency was to contain a number of pictures, illustrating different types of attack for use in training aircrew in recognition of target indicators, pathfinder technique and the selection of the correct aiming point defined by a pattern of markers. It was anticipated that further transparencies would eventually be required to ensure that up-to-date technique could be illustrated. (2) In a more detailed criticism of the prototype transparencies, the Training Branch expressed the opinion that the general representations of target-conditions, the shape, colour and brightness of fires, sticks of incendiaries and target indicators were satisfactory, and that the main point requiring amendment was the lay-out of the various target mosaics within the transparency. It was suggested that the first plate should represent different methods of marking on a variety of targets, and that the second plate should present the development of two separate attacks in four of five stages. (3)

By the end of October the Camouflage Branch had prepared sketches for the new transparencies and had experimented further on the production of the various 'target effects'. The sketch diagrams were considered at a meeting held at the Ministry of Home Security, Leamington Spa to discuss target models, when a number of criticisms were raised

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(1) Bomber Command File B.C./S.30893, Encl.53A.
(2) Bomber Command File B.C./S.30893, Encl.68A.
(3) Bomber Command File B.C./S.30893, Encl.72A.

and agreed upon. It was also decided to represent both the different marking methods and the development of an attack on one transparency only, which was to incorporate nine different mosaics.[1]

The complete issue of transparencies was received for distribution to stations in December, and a commentary was prepared by the O.R.S. and issued by the Training Branch with the plates.[2] The commentary described briefly the features shown on each mosaic, in particular the type of target-marking displayed, and the correct point-of-aim. The Air Ministry Unit in Applied Psychology had emphasised more than once that the maximum training value from these synthetic aids was only obtained when pupils had their results pointed out to them at the time. Accordingly, the O.R.S. arranged for a coloured key consisting of photographic reductions of the mosaics represented on the transparency to be prepared. On the key the correct point-of-aim was marked, together with circles of one half and one mile radius about the aiming point. The keys were to be held by bombing instructors. Whenever the Air Ministry Bombing Teacher was in use instructors were to take care to explain in discussions with pupils the extent to which their selected points-of-aim differed from the correct points. It was suggested that the most effective way of demonstrating to pupils their own performance was for instructors to shine a torch (masked to give a narrow pencil of light) on to the floor of the bombing teacher to mark the correct point-of-aim. The distance between this point and the image of the graticule could then easily be appreciated. It was recommended that records be kept of pupils' performance.

There can be no doubt that these transparencies were a far more effective method of portraying a target area under attack than the lantern slides which they replaced. They had the advantage of presenting at correct scales for operational conditions, a horizontal moving picture viewed through an air bomber's panel, at which pupils could aim. Pupils' results could be assessed, and their errors pointed out to them, all of which were immense advantages for training purposes over the slides, which merely served to demonstrate particular marking methods to a large audience. Moreover, the Air Ministry Bombing Teacher was standard equipment at all stations, while to display the lantern slides effectively, it was necessary for a room to be specially blacked-out, and for the projector to be screened so as to emit no extraneous light conditions which

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(1) Bomber Command File B.C./S.30893, Encls. 80A and B.
(2) Bomber Command File B.C./S.30893, Encls. 96A and B.

were not always obtainable at stations. Further, the transparencies were more realistic owing to the previous experience that had been gathered in producing slides, while the advice of the Air Ministry Unit in Applied Psychology ensured the choice of the most suitable target indicator patterns for training. The view was expressed that these transparencies should remain a standard training aid in the future.

Construction of Target Models

The construction of models of target areas for briefing crews on special operations had long been undertaken by the Central Interpretation Unit, and it was, no doubt, only the model-making effort involved that prevented them from being used much more widely. Proposals for the use of models as an aid to target identification were made on several occasions by the O.R.S. Their possibilities were briefly considered at a meeting in December 1941 with the Air Staff, to discuss problems of target identification (1) and reviewed at greater length six months later.(2) Examination then of a selection of the models made for special attacks suggested that there were great possibilities in their use for briefing on night operations. Existing Central Interpretation Unit models, however, while admirable in point of detail and accuracy of scale, were hardly suitable for demonstrating the appearance of a target at night, since they had been made with insufficient attention to texture, so giving an exaggerated appearance of contrast.

The Directorate of Camouflage of the Ministry of Home Security had also maintained a model-making department and in the normal course of work had studied in detail methods of reproducting textures approximating to those of natural surfaces as they appear at night. The Directorate, moreover, had a special viewing-room where models could be studied under a full range of moonlight conditions. The O.R.S. note made it clear that the best use would be made of models if crews were to study them under the actual conditions of illumination to be encountered, at distances scaled to normal operational heights, and at about the same angular aspect as they would view real targets. Such models should be at least ten feet square in size and should be provided with a surround which faded out to blackness. Illumination could be made directional by a simple projector-box fixed to a wall or ceiling, while moonlight could be simulated by use of green-blue filters. The note suggested that the model should be displayed to crews so as to illustrate the differences in contrast when a target was viewed with the moon, into the moon, across moon and vertically. It was felt that the details of lighting would need to be carefully worked out first by an illumination expert, but that this should not present great difficulty as the O.R.S. were already in close touch with the Illumination Department of the General Electric Company (G.E.C.) over kindred matters and that the suggestions should be tried out. The subject was of great interest to the Night Vision

/Training

(1) Bomber Command File B.C/S.28854, Encl. 1A.
(2) Bomber Command File B.C./S.27881, Encl. 11A.

Training Unit at Upper Heyford which expected to make considerable use of target-models for training in night vision, and in fact some months later requested their provision.(1) The models prepared by the Directorate of Camouflage met their requirements in regard to rendering of textures and colours of surfaces as they would appear at night.

At the end of 1943 the O.R.S. published a review of the problem of visual identification of targets and landmarks by night,(2) in which a short section on model technique as a training aid was included. It was stated that the chief defects of such aids as the epidiascope night-appearance-attachment and Air Ministry Bombing Teacher was that 'glints' from water and other natural surfaces could not be represented. Also, shadow variations over a target area, with different positions and elevations of the moon, caused considerable changes in ground appearance. It was considered that the labour involved would preclude the production of models for general issue, but the O.R.S. had asked the Camouflage Branch of the Ministry of Home Security, ~~which had already undertaken considerable investigations from the air on the appearance of the~~ [redacted] to experiment in the production of simple models textured to display the correct amount of shadow and glint when viewed under low illuminations. The construction of simple basic units, from which models of a number of target areas could be built up quickly, was also suggested. By such means the O.R.S. considered that it might at least be possible to provide Operational Training Units with models as well as with viewing rooms possessing suitably controlled illumination. By the time, however, that these proposals had been put to the Air Staff, the whole problem of target identification had changed with the introduction of target-marking techniques, and there was no longer a requirement for models to illustrate visual target identification. When the question of model construction arose again it was for the provision of displays representing target areas under attack

Target indicator markers were first used operationally in January 1943, and by the middle of that year it was clear that, although this new technique was of immense assistance as an aid to target identification, it was necessary to familiarise crews with the appearance of target markers and to provide them with demonstrations of attacks in progress. Only by such aids could they quickly gain the experience necessary to pick out at once a pattern of target markers from amongst a confusing background of fires, incendiaries and smoke, and to aim at the centre of the pattern. A number of other training aids discussed in this chapter ~~mono-~~[redacted] such as lantern slides, Air Ministry Bombing Teacher transparencies and the Bullseye demonstrations, were designed to provide the same experience.

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(1) BC/S.27781, [redacted] Encl. 92A.
(2) A.H.B./IIK/10/46.

The use of some form of model illustrating a target under attack, for briefing crews on the marking method to be employed on a particular night was proposed in an O.R.S. note of 20 August 1942.(1) The main objection to all accurate model-making of the kind implied here is the amount of time and labour necessary for construction of a sufficient number of models even to allow one for each base. To overcome this difficulty, the suggestion was made that there should be one large travelling demonstration van equipped with models and accompanied by a lecturer, that might visit all stations in turn to display different marking techniques. This suggestion, however, was not followed up.

A most important stage was reached in the analysis of the difficulties bound up with the use of target indicators by the publication of Bomber Command (2) O.R.S. Report No. 99 on the visibility and recognition of target indicators. Among other problems, this report considered in detail the factors affecting the visibility of target indicators, of which perhaps the most important physical factors were the effect of the design of the marker on its visibility, the extent of obscuration of buildings and other erections, and target conditions. It seemed clear that in oblique views, some candles would almost certainly be obscured by buildings, and that the effect would be most serious in the most densely built-up portions of a town. It was therefore desirable that the visibility of target-indicators in built-up areas should be carefully studied from various directions of view.

This report emphasised very strongly that training in recognition of target indicators should be a most fundamental part of an air bomber's training. Opportunity was afforded to as many crews as possible to see the target indicator demonstrations incorporated in Bullseye exercises, while lantern slides and Air Ministry Bombing Trainer transparencies were available which illustrated the appearance of a target area under attack. It was felt, however, that still further research into methods of synthetic training were required, and the report suggested that the Night Vision School at Upper Heyford might be the best place for such training to be given. The O.R.S. then proposed that the construction of models to represent a target area under attack should be reviewed jointly by the Directorate of Camouflage, the Night Vision Training School and the Air Ministry Unit in Applied Psychology at Cambridge. Such a joint meeting was held at Leamington Spa at the end of June 1944 when the construction of a model (at a scale of approximately 1 : 1000) of a target area was discussed, with particular reference to its use as a training aid.(3) It was decided that any model should be so designed that it might be photographed in oblique view to show target indicators and fires as they might appear to an air bomber

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(1) Bomber Command File B.C./S.28854, Encl. 86A.

(2) 'The Visibility and Recognition of Target Indicators.' Bomber Command O.R.S. Report No. 99. (A.H.B./II/39/1).

(3) Bomber Command File B.C./S.30893, Encl. 53A.

amongst buildings at night. This would provide a set of slides suitable for illustrating, both the Bomber Command O.R.S. Report No. 99 and also a memorandum recently issued to units by the Training Branch.

The above proposals were discussed with Air Staff and on the advice of O.R.S., Training Branch requested Air Ministry at the beginning of July to authorise the construction of both model and slides.(1) The O.R.S. undertook to maintain a close liaison with the Camouflage Branch over the construction of the model, which was to represent a typical Ruhr town. Care was taken to ensure that the right proportion of the different types of built-up area were used in the model. The standard zone maps being taken as a guide. Many night photographic mosaics and also colour film were available as a guide to the appearance of fires, incendiaries and target indicators and general target conditions. It was considered that this model should be photographed in oblique view to illustrate the appearance of the target area at bombing angles of 30°, 45° and 60°, and the Training Branch requested the production of 180 sets of slides.(2)

The completed model was inspected on 6 November 1944 by a meeting of representatives of the Training Branch at Headquarters Bomber Command and from Air Ministry and from the O.R.S., when the view was expressed by those present who had operational experience, that it represented the appearance of a target area very adequately.(3) The model showed target indicator markers, fires and incendiares burning among buildings, while effects of smoke and haze were also simulated. It was pointed out that by use of alternative electrical circuits at the back of the model, various target indicator and incendiary patterns could be illuminated, enabling a number of different methods of marking to be represented on the same model. In view of the general agreement on the suitability of the model, production of the 180 sets of slides was pressed ahead, and these were delivered to the Training Branch a month later for distribution to all stations.

It was felt by those present at the meeting that the very realistic rendering of a target under attack conveyed by the model, entirely justified the policy of constructing a few exceptionally carefully made target models, to be held at a central unit where the most use could be derived from them. Slides and illustrations depicting the different types of target marking that they displayed, could be used to familiarise air crew with their appearance. In fact, one essential aspect only was lacking in the Leamington model, namely, it portrayed

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(1) Bomber Command File B.C./S.30893, Encl. 54A.
(2) Bomber Command File B.C./S.30893, Encl. 54A.
(3) Bomber Command File B.C./S.30893, Encl. 80A.

a static picture, or series of such pictures, and could not be used to illustrate the progressive development of an attack. A synthetic trainer had already been constructed at No. 54 Base, R.A.F. Station Coningsby, which depicted with some success the development of controlled visual marking as practised by No. 5 Group. Use of a revolving table and a sound-commentary enabled the progress of an attack to be displayed for training Master Bombers. On the other hand the Coningsby model, though accurate for scale, had been constructed without any special attention to texture or 'glint' of the different surfaces represented. Nor was there any device for representing haze or smoke. It seemed clear that by a pooling of resources it should be possible to make quite quickly a model that would display admirably the whole progress of an attack and give an accurate presentation of ground surfaces, target conditions, haze and smoke as they appeared on operations. To do this it was necessary to combine the experience gained in model-making at the Directorate of Camouflage, with the resources of No. 54 Base for all the electrical equipment required, and a meeting with members of the Camouflage Branch and of Air Staff Training, was organised by the O.R.S. to discuss the project.(1)

It was apparent at this meeting, held at Coningsby at the beginning of March 1945, that such a project could be achieved, and the Training Branch at No. 5 Group requested the production of a target model. It was agreed that the new model should represent a target area, some eight miles across, as seen from normal operational heights, the actual scale of the model being about 1 : 3000. A centre piece of about six feet in diameter was to be movable so that it could be replaced by alternative models representing a number of different targets, the surround being common to all. It was required to illustrate both 'off-set' and 'direct' marking and the 'effects' to be reproduced included flares, target indicators, bomb-flashes, fires, decoys, gun-flashes, flak burst and searchlights. It was also thought desirable to reproduce haze and smoke. The general requirements, which were to specify the targets to be represented, and the details of marking were to be drawn up by No. 54 Base. Plans illustrating the requirements were to be prepared by the O.R.S., who would pass them with all the other target information necessary, to the Directorate of Camouflage at Leamington. All the carpentry and painting of the model was to be undertaken at Leamington while No. 54 Base was to be responsible for all the electrical fittings. The following types of attack and target were chosen:-

/'Off-set' ....

(1) Bomber Command File B.C./S.30893, Encl.100A.

'Off-set' marking on a town	Ulm
Marshalling Yard	Aschaffenburg
Docks	Harburg
Oil Refinery	Ruhland
Linear target (canal or viaduct)	Dortmund-Ems Canal

Photographs of these five targets and other information were supplied to the Directorate of Camouflage at the end of March, and with the benefit of the experience of production of one target model already, the work proceeded quickly. The common surround and one centrepiece were finished by May, when the number of targets was reduced to three, in view of the conclusion of the war in Europe. The remaining two models were finished and despatched to Coningsby by the end of June, for the electrical assembly.

There can be no doubt that this Coningsby trainer was by far the most successful of the many training aids designed to instruct aircrew in target marking. Though elaborate in construction it did not take unduly long to produce (three months) and possessed the great advantage of portraying all stages of the development of an attack, rather than a static picture. It was of particular value at a Pathfinder Base, for the greatest benefit would be derived from it by crews practising to be Master Bombers or Marker Leaders, rather than Main Force crews. Further, additions to the number of alternative centrepieces will enable varieties of marking to be displayed in relation to different types of target, in a variety of surroundings. The O.R.S. urged that the Coningsby Trainer should be developed as the standard training aid for bombing on markers.

Psychological Investigations into Problems of Bombing on target indicators and Production of Cambridge Synthetic Trainer

The first approach from O.R.S. to the Air Ministry's psychological advisers was made in the summer of 1942, when a meeting was arranged with Professor Bott at Air Ministry.(1) The O.R.S. were interested in two aspects of the psychologists' work, namely, the possible application of psychological principles to the solution of problems of target identification and the best tests to apply in the selection of personnel for certain specialised duties, such as those of air-bombers and navigators. The question of the most suitable training for air-bombers was also discussed at this meeting. In the matter of training in target identification the Air Ministry Psychological Adviser was unable to particularise in detail the form that the course should take, but gave some general guiding principles. Thus, training should be made as realistic as possible by simulation of actual operational conditions, and the training programme should come up for

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(1) Bomber Command File B.C. 27881, Encl. 1A.

review at frequent intervals, as operational conditions changed. The continual use of 'scoring' methods and the introduction of the competitive idea into training methods was important, for measuring the progress of individuals and the efficiency of the course as a whole. Simulation should be kept to bare essentials and not over-elaborated.

It became clear in the discussion that the Psychology Unit had under consideration the question of selective tests for aircrew personnel, and the Unit was concerned to know what qualities are of importance for successful air-bombing, navigation and the like, to construct selection tests. It was important that there should be the closest correlation between selection test and operational practice, which could only come from analysis of operational data. It was felt that in this connection that the O.R.S. could provide an invaluable link between the psychological unit, training schools, and operational personnel. However, in spite of the community of interest which was apparent at the meeting, the main contacts between the O.R.S. and the Psychology Unit in the next year and a half were on the matter of Night Vision Training, which are described earlier in this chapter.

With the introduction early in 1943 of target indicators, operational practice entirely changed so far as air bombers were concerned, and it was in connection with problems of the visibility of target indicators which were under review by O.R.S. at the close of the year that contact with the Air Ministry Unit in Applied Psychology was resumed. At a meeting held at the M.A.P. on 23 February 1944 to consider the visibility of target indicators, the operational problem, as it confronted an air-bomber, was discussed. The choice of the centre of a group of markers as point-of-aim, was by no means an easy one to make in the limited time available on the run-up to a target, bearing in mind the distracting effects introduced by background lights, fires and incendiaries, by drifting cloud and smoke which might obliterate part of the target, and by changes in the pattern introduced by the release of new markers. There was also the question of how best to mitigate the effects of decoy markers used by the enemy. Dr. Mackworth of the Air Ministry Unit in Applied Psychology said that the shape of the pattern of markers would affect the ease with which they were recognised, and that a series of experiments could be devised to determine the best pattern, the effect on the estimated Mean Point of Impact, of obscuring parts of the cluster, and the effect of mixing colours in various proportions. The meeting agreed that such experiments should be undertaken. (1)

By the end of March a simple apparatus had been rigged up by the Air Ministry Unit in Applied Psychology, to represent the effect of

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(1) Bomber Command File B.C./S.30893, Encl. 16B.

approaching a pattern of coloured lights (simulating target indicator markers) at a speed and height scaled to operational conditions. Twenty three R.A.F. cadets were tested on this apparatus, each being allowed three seconds in which to mark the estimated centre of the pattern. Apart from systematic errors, it was found that the random error was distributed far more elliptically than the markers, being scattered four times as much fore and aft as laterally. This effect suggested that a pattern, maintained by successive backing-up would itself spread elliptically. It was felt that comprehensive tests of this kind, which were quite simple to organise, might bring to light facts that would be of value for training and briefing air bombers and that more realistic tests should be undertaken using the optical system of a Mark XIV bombsight.[1] The first factors to be tested were three precisions of marking, the effect of a distracting background of flares, the use of different coloured markers, and of different patterns of markers, giving in all 24 conditions.[2]

At the end of May 1944 an O.R.S. report on the visibility and recognition of target indicators were issued which contained an appreciation of the difficulties confronting air-bombers. It was suggested that since visual identification of targets had become less important the Psychology Unit should take on, as an additional investigation, research into training in colour discrimination near the colour threshold.[3] However, it was soon found that use of differently coloured markers had a negligible effect on the choice of mean points of impact.

In the course of the next few months continual liaison was maintained with the Psychology Unit, and much information was supplied by the O.R.S. regarding appearance of target-markers, target-conditions and the like. It was suggested that the first conditions to be investigated should be a 'Newhaven' attack reverting to 'Parramatta' and the late stages of 'Newhaven' marking. Patterns of markers and other lights were represented by a number of appropriately coloured celluloid discs, arranged to cover apertures in a black mount, the apertures being illuminated from below. At a meeting held at Cambridge at the end of June to review the work, it was stated that preliminary tests with A.T.C. cadets showed that the subject's ability to estimate the centre of a pattern varied with the type of pattern, with the direction of approach to a given pattern, and with the degree of dispersion of a pattern for a given arrangement of target indicators. For subjects

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(1) Bomber Command File B.C./S.30893 Encl. 23A.
(2) Bomber Command File B.C./S.30893 Encl. 28A.
(3) 'The Visibility and Recognition of Target Indicators'. Bomber Command O.R.S. Report No.99. (A.H.B./II/39/1).

with normal colour vision there was little difference in their choice of centre using either red or green markers.(1) It was agreed at this meeting that the investigations be continued and that operational air bombers from No. 3 Group stations be made available as subjects for the tests. It was also decided that greater realism should be attempted in the representation of a target area by introducing a background of fires, incendiaries and glow. In this connection a valuable liaison was affected with the Camouflage Branch of the Ministry of Home Security at Leamington, whereby the Camouflage Branch were to supply realistic transparencies for use in the trainer under development at Cambridge. In their turn, the Unit in Applied Psychology were to advise on the selection of target indicator patterns and grouping, considered to provide interesting and difficult cases, which would be suitable for use as lantern-slides and for transparencies for the Air Ministry Bombing Teacher, which were then being prepared.

A first report from the Psychology Unit on their experimental findings in connection with the problem of estimating the mean point of impact of target indicators, was received on 10 August 1944 (2) and a considered report was issued in September. (3) It was agreed that this should be distributed to the Flying Personnel Research Committee and the Medical Researdh Council. In this report, answers were attempted, on the basis of experimental findings, to a number of questions of which the most important were: how accurately can estimates be made of the mean point of impact of various patterns of target indicators? which factors give difficulty in estimating the M.P.I. and what are their relative importance? and what training methods are most promising in improving accuracy in estimating the M.P.I? After describing the extensive investigations that had been undertaken, the following conclusions were reached:- that pattern-shape and compactness were the most important visual factors determining whether the M.P.I. of a pattern can be accurately placed. Poor shape and lack of compactness in a pattern interacted with each other to impair accuracy still further. The direction of approach to a given pattern was also of importance. The human factor was just as important as the differences between patterns. Marked differences of ability to do this kind of work were found between individual aircrew.

It was suggested that an approximate index to the difficulty likely to be experienced by air bombers on any given pattern could be obtained from a measure of the average distance of target indicators from their true M.P.I., and the distance between the two most widely separated markers. The observed fact that an increase in the number

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(1) Bomber Command File B.C./S.30893, Encl. 53A.
(2) Bomber Command File B.C./S.30893, Encl. 62A.
(3) Bomber Command File B.C./S.30893, Encl. 85A.

of fixed points in a pattern increased the difficulty of M.P.I. estimation, together with the importance of the human factor, underlined the need for further analysis of the best number of markers to use, and for the greatest care in the training of air-bombers. It was, moreover, possible to draw from the experiments further preliminary conclusions, as follows: firstly, that in tests, without specific verbal instructions, air-bombers made capricious disregard of certain markers, the markers that were neglected varying with different individuals; secondly, that under the quiet conditions of a laboratory experiment certain subjects obtained persistent errors of 1000 yards or more in aiming at a pattern of lights of the appropriate size and scale to represent a target-area seen from between 12 and 20,000 feet.(1) The scale of error revealed in laboratory experiments suggested that there was great room for improvement of accuracy in assessing aiming-points, defined by coloured markers. It was suggested that it was important to see how widespread were such errors and that a larger and more representative sample of air-bombers should be studied.

The attention of the Training Branch was specially drawn by the O.R.S. to these results, since it was felt that in the light of the work undertaken by the Psychology Unit, better methods might be devised for training air-bombers in view of the great change in operational conditions that had taken place. The Psychology Unit had advised on the choice of patterns of markers to be used in the transparencies in preparation at this time for the Air Ministry Bombing Trainer and the members of the Unit strongly emphasised that a definite system of scoring should be adopted for assessing pupils' performance, and that pupils should be kept acquainted with their own results. These transparencies, though very valuable for representing target conditions, did not provide the opportunities, to practice estimating the mean points of impact of a large number of different groupings of markers, which it was now felt were essential to an air-bomber's training.

The possibility of adapting the apparatus developed by the Psychology Unit at Cambridge for testing pupils' assessment of the M.P.I. of a pattern of lights, was therefore considered. The views of the Psychology Unit were that it was possible to train people to select the centre of a groups of points with increasing accuracy, and that this improvment was not confined to the patterns on which pupils had been trained. The evidence suggested that pupils would not improve with practice unless they were given their results immediately after each attempt at a particular pattern. It was proposed that methods of introducing this important knowledge of results factor in training should be further investigated by the O.R.S. (2)

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(1) Bomber Command File B.C./S.30893, Encl. 83A.
(2) Bomber Command File B.C./S.30893, Encl. 95B.

Matters were carried a stage further when the O.R.S. arranged, at the request of the Training Branch, a meeting with the Air Ministry Psychology Unit at Cambridge, towards the end of February 1945. This meeting was also attended by members of the Training Branch and the bombing leaders of Nos. 5 and 8 Groups. The results of earlier experiments on the training by air-bombers in estimating aiming-points defined by patterns of coloured markers was discussed with particular reference to the use of synthetic training aids. The Director of the Psychology Unit expressed the view that the apparatus they had devloped was an instrument of definite value in training, and recommended its introduction for air-bombers' instruction and practice. The meeting agreed that the Cambridge apparatus was a most useful synthetic training device, which could be developed as a standard trainer for use in connection with target indicator marking. Estimation of aiming-points defined by patterns of coloured markers could more usefully be given on this apparatus than on the Air Ministry Bombing Trainer. As a result of the meeting, the Training Branch arranged for a contract to be placed for 25 models of the Cambridge Trainer, and it was arranged that Dr. Mackworth of the Psychology Unit should write a short memorandum of instructions for operators on the use of the apparatus.

In spite of the priority given to the contract the order was not completed by the end of the war in Europe. When eventually in June, the models were to hand,it was decided to adopt officially this method of synthetic training, and they were allotted to No. 7 Group with a small number maintained in reserve for use in training air-bombers who would be operating in the Far East. The instructional memorandum on the M.P.I. trainer was in the meanwhile completed,(1) and all No. 7 Group bombing leaders were given a short course on the use of the apparatus and on training procedure. The instructions pointed out that merely repetitive practice on the machine would not lead to any improvement at all in accuracy. Bombing leaders were expected to take an active part in the training and to show their pupils the correct answer after each assessment.

In the meanwhile, the Psychology Unit were completing an account of their investigations on the synthetic training of Pathfinder air bombers. The O.R.S. suggested that it would be valuable to attempt to correlate individuals' results on the apparatus, with records of their performance on operations. However, in spite of an analysis of the records of a large number of crews in target-marking, the evidence proved insufficient for any useful comparisons to be drawn. The account was finally drawn up in July 1945 as an Air Ministry Psychology Unit report on 'The synthetic training of Pathfinder air-bombers in visual centring on Target Indicators'.(2) A summary of /the

(1) Bomber Command File B.C./S.30893, Encl. 109A.
(2) Bomber Command File B.C./S.30893, Encl. 111A.

the conclusions is as follows: air-crew with no previous experience of visual centring improved markedly with practice on the M.P.I. trainer, and synthetic training of flying personnel without experience of visual centring improved their subsequent performance on entirely different patterns. Again, experienced operational air-bombers steadily improved with repeated synthetic training on the same pattern. Repeated courses of synthetic training for operational air-bombers showed, either that the effect of the initial training lasted over a period of some months, or that more operational experience had improved ability on the synthetic device. Experiment also confirmed the previous opinion that pupils tended to assess the M.P.I. of a number of points by considering the points as defining an area, and estimating the centre of that area. Special training was necessary to overcome this tendency, which displaced the M.P.I. of a pattern away from the true position towards any outlying markers.

CHAPTER 10

VISUAL BOMBING TRAINING

Introduction

Before January 1944, the O.R.S. took only a slight interest in the accuracy and use of bombsights. Data on the accuracy on practice bombing exercises were published monthly by the various Bomber Command groups in their summaries but although considerable doubt was felt as to the veracity of these figures the O.R.S. carried on no corresponding analysis. Up to this time the vast bulk of Bomber Command activity had been carried out by night and it was obvious from the magnitude of the bombing errors as assessed from night photographs that bombsight accuracy was a negligible factor in the overall accuracy of night bombing.

About the beginning of 1944 it became necessary to review this policy in view of the rather disappointing results achieved in attacks on special lightly defended targets in northern France. It should be made clear at this point that Bomber Command squadrons were almost completely equipped by this time with the Mark XIV bombsight, one notable exception being No. 617 Squadron of No. 5 Group which was fitted with the Stabilised Automatic Bombsight Mark II. On these raids the No. 617 Squadron results were generally satisfactory but the results obtained by the squadrons equipped with the Mark XIV sight were very poor, much poorer in fact than the figures quoted in the group monthly summaries for practice bombing accuracy. Moreover, the standard being achieved in practice with the Mark XIV (about 250 yards at 12-15,000 feet) was also very poor compared with the accuracy obtained in the development trials of the bombsight (120 yards at 12-15,000 feet). It was obvious therefore that the full capabilities of the Mark XIV bombsight were not being attained on operations and that there was an urgent need for the O.R.S. to investigate the discrepancy and discover its causes.

The order of the errors achieved with the bombsight on operations was known with some certainty although it was fully appreciated that part of the error was due to lack of a unique aiming point. Considerable doubt existed, however, about the practice bombing figures produced in the group monthly summaries. The precise method of analysis was not known but it was suspected that there was considerable laxity of treatment of gross errors and that poor exercises were frequently omitted altogether. A study of the published figures showed that there was a large component of wind finding error which partly explained the large difference between crew practice accuracy and development trial accuracy. It seemed, moreover, that the factor of

/wind-finding

wind-finding accuracy on operations might have a considerable bearing on the problems and it was decided to institute two parallel investigations i.e. firstly, a determination of winds used on operations against lightly defended targets and secondly, an analysis of practice bombing. Of these two investigations the second one forms the basis of the following section of the chapter.

Before a start could be made on the problem of analysing practice bombing results it was necessary to arrange for systematic returns of practice bombing results to be made by the various groups to O.R.S. Headquarters Bomber Command. An O.R.S. representative from the latter visited each of the groups in turn and discussed the layout of the returns and the data required for full analysis with the Group Bombing Leaders and the Group O.R.S. representatives. It was not possible to secure complete uniformity throughout the command because training policy at each group was the responsibility of the group Air Officer Commanding and it was inevitable that differences should occur. For example, although information on range results was available in a very convenient form in No. 5 Group, i.e. teleprinter forms direct from the range, it was always difficult to obtain adequate wind information from No. 5 Group.

Considerable progress was made on the analysis of practice results using these returns from the groups. The returns, however, showed many difficulties and revealed many faults in procedure both in the conduct and analysis of individual exercises and in the collective analysis of results on a squadron and group basis. The order of these factors given above corresponds with their relative importance and the method of approach to them by the O.R.S. will be discussed in the same order.

Conduct and Analysis of Bombing Exercises

It was found that the training instructions in force at the time were not very strictly adhered to but that they were more rigorously carried out in the Operational Training Units than in the squadrons. These instructions stated that a full practice should consist of dropping eight practice bombs from the same height and each on a different aircraft heading. The same wind, i.e. the best wind available, was to be used throughout the exercise and it was to be checked by taking a smoke puff wind during the exercise. Every effort was to be made to carry out exercises from a height greater than 10,000 feet.

Due to the varying degrees of enthusiasm for practice bombing in the groups the amount of practice bombing varied widely from group to group and from squadron to squadron. Due to the limited time available for practice caused by operational commitments and by bad weather, exercises were frequently curtailed and less than eight bombs were dropped. It was frequently apparent that insufficient care was taken to spread out the aircraft heading on the individual bombing runs and the height of bombing was, generally, well below 10,000 feet. A most important omission, frequently apparent, was the failure to take a smoke puff wind thus making an exact analysis of the exercise impossible. There was considerable laxity in the recording of large errors on the range. Bombs which were off the range of the quadrants were often merely marked down as 'not recorded' and were not distinguishable from bombs which fell within range of the quadrants but were not recorded because of their failure to explode or for some other technical reason. The O.R.S. recommended a more rigid adherence to the training instructions for the conduct of exercises.

The primary aim of bombing analysis is to determine the cause of the bombing errors, and to recommend appropriate action for avoiding such errors. It follows, therefore, that the analysis, to be most effective, should be carried out as soon as possible after the actual exercise and that the crew of the aircraft should be on the spot to follow the analysis and assist in the interpretation of the results. It is obviously essential that the bombing leader, to supervise the analysis, must have a very sound knowledge of the bombsight and of the correct method of analysis. The existing publications covering bombing analysis did not, in the opinion of the O.R.S. , approach the problem of analysis from the best angle and it was suggested that a representation of the principles starting from the bomb-plot was required; in other words the analysis should be built up around the effects and not the causes. The O.R.S. therefore proceeded to investigate the current situation with respect to bombing analysis with the particular object of devising a general method of analysis on these lines.

The uncertainty of the pseudo-wind vector error was stressed and the causes of the uncertainty given as the inaccuracy of the plotting of T2 [1] and the unreliability of the position of the mean point of impact of eight bombs. It was suggested that the minimum pseudo-wind vector which could be considered significant was 60 yards. [2]

Owing to unreliability of the position of the M.P.I. and to the fact that certain large errors were not recorded, the O.R.S. considered that the pseudo-wind vector error could not be properly eliminated before proceeding to the next stage of the analysis. [3] It was therefore suggested that a second vector target, T3, should be obtained by vectoring out such known specific errors as:-

(a) Any error between that set on the bombsight and the correct setting based on the navigator's wind.

(b) Any error due to a known desynchronisation.

(c) The known trail of the instrument.

If all bombs were replotted about T3 and on a common heading, there would be, in general, a mean point of impact displaced from T3 demonstrating the presence of a line error, to port or starboard, and a range error, either undershoot or overshoot. [4] A simple method of performing the replotting was described and a series of tables was given which gave the possible causes of each of the possible observed results of analysis i.e. systematic line error, systematic range error, random line error and random range error.

Shorly after this paper was written the Mark XIV wind was introduced for use with the Mark XIV series of bombsights. This false wind was designed to correct the trail error mentioned above and therefore the arguments in favour of plotting T3 had to be reviewed. This step removed the greatest source of pseudo-vector error since the two remaining corrections were of infrequent occurrence and it was therefore decided that it was practicable to rule out T3 altogether and to replot the bombs about the M.P.I. when analysing for range and line errors. When this point was settled all the suggestions and recommendations were embodied with some elaboration in a excellently produced booklet with many diagrams called 'Analysis of Bombing Errors with the Mark XIV Series of Bombsights'. This publication, issued by Training Branch, Bomber Command in July 1944, contained appendices fully explaining the Air Position Indicator method of finding a wind during bombing, the centroidal method of finding 'mean correct wind' using all available winds, diagrams of typical

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(1) T2 - an imaginary point of aim associated with calculations to reduce the error to a standard basis.
(2) 'Assessment of Practice Bombing Accuracy. Mark XIV Bombsight.' Bomber Command O.R.S. Memo. No. M.13. (A.H.B./IIH/241/22/3).
(3) 'Bombing Accuracy with Mark XIV Bombsight.' Bomber Command O.R.S. Report No. S.220 (A.H.B./II/39/1/1).
(4) 'Causes of Irregular Release with the Mark XIV Bombsight in Practice Bombing.' Bomber Command O.R.S. Report No. S.219. (A.H.B./II/39/1/1).

plots showing typical errors (these were selected by the O.R.S. from actual bombing exercises) and several other relevant subjects. Certain of the material in the publication was provided by the Instrument Department of R.A.E., and also by the chief instructor of the Bomber Command Analysis school when it was formed. The issue of the publication served to standardise the general method of bombing analysis and to eliminate many of the undesirable practices which were in use. It also formed the basis for the courses of instruction on bombing analysis.

Whilst the O.R.S. had been engaged upon the work described above the Training Branch at Bomber Command had decided to form an Analysis School to instruct bombing leaders and others in the principles and sources of error of Mark XIV bombing. The bombing leaders' course at this Analysis School was largely built up around the Bomber Command Armament Note on Bombing Analysis.(1) The O.R.S. was in favour of establishing such a school and advanced the following suggestions as to its terms of reference.

(a) To determine the general lines along which practice bombing should be conducted throughout the Command.

(b) To design and standardise practice bombing returns by squadrons to groups and by groups to headquarters.

(c) To instruct unit bombing leaders in the principles of bombing analysis, and on the methods to be followed in squadrons.

(d) To maintain the Command's bombing accuracy records.

(e) To advise Bomber Command's Training Staff on any findings requiring policy action.

(c) and (e) were considered to be the two most important of these objects and the Bombing Analysis School was formed in July 1944 with these objects as its primary functions. It later assumed some work under heading (b) and (d) thus relieving the O.R.S. of a considerable amount of routine activity. This aspect of its work will be mentioned below under the heading of 'Collective Analysis'.

Collective Analysis

Before any improvement in the standard of accuracy of practice bombing could be attained it was essential to unify the system of bombing analysis and the method by which this was achieved has already been described. To detect the resulting improvement, however, a sound method of collective analysis was necessary and due to the smallness of the genuine trends over short periods the method chosen needed to be both accurate and sensitive. The search for such a

/method

(1) Bomber Cmd. Armament Training Notes, Pt.I, Bombing Serial No. 4.

method of analysis and, having decided upon one, to have it adopted by the Command was one of the major tasks of that section of the O.R.S. devoted to the study of practice bombing. Various systems were in use throughout the Command for the collective analysis of bombing results and all of them suffered from considerable sources of error particularly in respect of gross errors which were frequently left out of the analysis altogether. It was therefore impossible to compare, with any degree of confidence, average errors quoted by different groups.

As an interim measure designed to standardise the current procedure for collective analysis the O.R.S. made some recommendations on the subject in the paper on bombing analysis. Three definitions were given.(1)

"(a) <u>The individual crew error</u> is the average error of all bombs dropped in an exercise converted to 20,000 feet.

(b) <u>The monthly squadron average</u> is the average error of all bombs dropped by the squadrons during the month converted to 20,000 feet.

(c) <u>The monthly group average</u> is the average error of all bombs dropped by the group during the month converted to 20,000 feet."

The practice of taking the average of exercise averages to obtain squadron and group figures was condemned because of the varying number of bombs in each exercise. A standardised procedure for taking account of bombs which fell too far from the target to be measured was recommended, i.e. they were to be given an nominal error of 600 yards at 20,000 feet and included in the averaging process (at the same time the percentage of such bombs of the total number was to be kept). It was further recommended that the analysis should be undertaken at some central establishment and it was eventually undertaken as a subsidiary commitment by the Bomber Command Analysis School.

When a sufficient quantity of practice bombing results had been received by the O.R.S. a basic investigation was begun with two primary objects in view, firstly, to discover the causes of the poor accuracy achieved in the Squadrons and, secondly, to devise a sound method of collective analysis.(2) The second of these objects forms the basis of this section.

The distribution of crew errors, component erros, systematic line and range errors and component random errors over each 1000 feet height band were examined for a large number of practice exercises in which five or more bombs were dropped. It was found that the crew

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(1) 'Analysis of Practice Bombing'. Bomber Command O.R.S. Memo. No. M-17.
(2) 'Interim Report on the Analysis of Practice Bombing Errors with the Mark XIV Bombsight'. Bomber Command O.R.S. Memo. No. M-15. (A.H.B./IIH/241/22/3).

errors within any one height band did not conform exactly to the Gaussian law of errors, there being rather more large errors than would be expected in such a distribution. It seemed therefore that the best direct parameter that could be calculated was the 50 per cent zone. At the same time it seemed that the main point of interest in this type of analysis was the density of bombs in the immediate vicinity of the target and that a parameter more directly based upon the assumption that the inner core of the bomb distribution was approximately a normal one - an assumption which was fairly well justified by later investigation was the best one to use. For each height band the number of bombs within circles of radii 100, 141, 200, 282 and 400 yards, centred on the target, were counted. From the theory of the normal distribution it was possible to obtain an estimate of the standard deviation of the distribution from the ratio of the numbers within successive circles. From the standard deviation the value of the total number of bombs comprising the normal distribution could be calculated and the excess of the observed total number of bombs over the calculated total number might be regarded as gross errors and expressed as a percentage of the total number dropped. The standard deviation could also be used to determine other parameters, e.g. 'the effective 50 per cent error' to describe the inner core of the distribution.

This idea was developed in a later unpublished paper on practice bombing errors with the Mark XIV bombsight.(1) This was a very full account of the progress of all aspects of analysis of practice bombing in the Command. At this stage, however, the development of the method of collective analysis is the only portion of this paper to be considered. The practice results for the period April to June 1944 were subdivided into groups, squadrons or heavy conversion units and into months. Height bands of 1000 feet width were taken and the errors were classified, as before, into intervals of 100, 141, 200, 282, and 400 yards. Two parameters were quoted throughout the paper. The first, namely the overall 50 per cent error, was quite simply obtained by observation, i.e. in which interval the 50 per cent boundary occurred, and by interpolation to estimate at what point within the interval the exact limit of the 50 per cent region occurred. The second paramater, defined as the 'effective 50 per cent error', was calculated on the assumption that the inner portions of of the distribution (i.e. of less than 300 yards radius) were normal. Four estimates of the 'effective 50 per cent error' were obtained

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(1) 'The Bombing Errors using the Mark XIV Vector Bombsight on Practice.' Bomber Command O.R.S. Memo. No. M.14. (A.H.B./IIH/241/22/3).

from the four ratios of numbers of bombs corresponding to the following pairs of circles 100-141 yards, 141-200 yards, 200-282 yards and 282-400 yards. In a few cases the estimate of the 'effective 50 per cent error' from the 100-141 yards pair of circles was rather high due to a tendency of certain of the distributions (notably at 8000 feet and above) to be slightly hollow-centred. Apart from these odd cases the results obtained for the 'effective 50 per cent error' were less than the overall 50 per cent error as would be expected and yielded a positive percentage of gross errors. It was found that results obtained for small samples of bombs were most erratic and that to determine the 'effective 50 per cent error' with any confidence large samples were essential. This was achieved by a suitable widening of the height bands.

The method received one further modification of application rather than principle and that was the substitution of 'effective average error' for the 'effective 50 per cent error'. Since from the nature of the method the parameter actually obtained in the first instance is the 'effective standard deviation' and since it is assumed that the core of the distribution is both circular and normal the deriviation of the 'effective average error' or the 'effective 50 per cent error' merely involves the multiplication of the standard deviation by appropriate constants. The method was described fully in an unpublished memorandum (1) in which a graph was given for converting the ratio of numbers of bombs within successive circles directly to 'effective average error'. A second graph for estimating the percentage of gross errors from the 'effective average error' was also given. A description of the method and its justification were also described in an Appendix to Bomber Command O.R.S. Report No. S.220. (2)

This method was never adopted officially in Bomber Command but when the Bomber Command Analysis School undertook the work of collective analysis they arranged all practice bombing errors in suitable height bands and in the appropriate error intervals (i.e. 100, 141, 200 yards etc.) so that the application of the method was possible with a minimum of labour. From the raw material supplied by the Analysis School the practice bombing results were subsequently analysed by the O.R.S. into 'effective average errors' and corresponding gross error percentages. From the middle of 1944 onwards this method was used by the O.R.S. for the study of inter-group and chronological variations.

Variation of Bombing Accuracy with height using the Mark XIV Bombsight

With a vector bombsight there is bound to be a deterioration of bombing accuracy with increase of height. At the same time it is necessary to compare bombing performances at different heights and to

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(1) 'Assessment of Practice Bombing Accuracy. Mark XIV Bombsight.' Bomber Command O.R.S. Memo. No. M.13. (A.H.B./IIH/241/22/3).

(2) 'Bombing Accuracy with Mark XIV Bombsight.' Bomber Command O.R.S. Report No. S.220. (A.H.B./IIH/241/22/14).

do this it is necessary to know the law governing the change of accuracy with height. Once the appropriate law is known the standard procedure is to convert all errors to a common height for purposes of comparison. This common height was originally 10,000 feet in Bomber Command but it was subsequently changed to 20,000 feet to facilitate the comparison of practice and operational bombing results. The height/error law used with the Mark IX bombsight and initially with the Mark XIV, was that the error was proportional to the square root of the height. This law was partly empirical and partly theoretical.

Early in 1944, shortly after the general introduction of the Mark XIV bombsight the O.R.S. was dissatisfied with the square root law as it seemed from a study of practice bombing results that the conversion of errors from low heights seemed to lead to an under-estimation of their accuracy. In May 1944 sufficient results had been analysed to make a closer study of the height/error variation possible. The overall 50 per cent error was plotted against height and attempts were made to fit the best curve, the choice lying between a parabola and a cubic. It was obvious that the accuracy at greater heights was greater than was indicated than the extrapolation of the parabola which fitted the lower results. Yet a significance test indicated that the parabola was as good a fit as the best-fitting cubic. The data on the higher height bands was scanty and so no conclusions were advanced at this stage. When the Bomber Command Armament Note on Bombing Analysis was issued a nomogram based on the original square root law was included in it.(1)

In August 1944 a similar investigation was carried out. The overall 50 per cent error was again the parameter used for the investigation. The overall 50 per cent error was plotted against height on logarithmic graph paper and the best-fitting straight line was drawn through the points. If the height/error variation is taken to be of the form

$$\frac{\text{Error1}}{\text{Error2}} = \left(\frac{\text{Height1}}{\text{Height2}}\right)^{A}$$

When A is a constant, then the slope of the best straight line is numerically equal to A. The spread of results was considerable and it was obvious that they could not yield a firmly established law yet, clearly, the variation was considerably less than would be expected with a square root law. The procedure was carried out for several groups over a period of two months and of the various indices obtained 0.36 was selected as being the most representative.

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(1) Bomber Cmd. Armament Training Notes, Pt.I, Bombing Serial No. 4.

A new height conversion nomogram was constructed on the basis of this new index and it was issued to units for general use in August 1944. The O.R.S. suggested that the variation would have to be closely studied with a view to amending the nomogram if a significantly different law were arrived at.

An investigation of the height/error variation in No. 4 Group's results for September 1944 by the method described above gave an index of 0.34 which was in quite good agreement with the previous results. On this occasion the 'effective 50 per cent error' was used to measure the variation.

In Bomber Command O.R.S. Report No. S.200 (1) a further attempt to check the accuracy of the index is described. A large sample of No. 5 Group results covering the period from July to November were used for the analysis. The results for each month were separated into 2000 feet height bands and for each band the 'effective average error' was determined. The 'effective average errors' were plotted against height on logarithmic graph paper and an index corresponding to each of the five months was obtained. They were as follows: July 0.23, August 0.31, September 0.25, October 0.34, November 0.30. The mean of these indices is 0.29 and apart from the July result the scatter about the mean is insignificant. The difference between these results and the results from the April to June sample which gave the index 0.36 was barely significant and it was not considered advisable to alter the nomogram at this stage. A suggestion was made that although the overall results between 2000 feet and 18,000 feet definitely indicated a variation less than the square root law, the variation between 12,000 feet and 20,000 feet might approximate more closely to the square root law. However, the available data were too scanty to investigate the suggestion thoroughly.

In August 1945 a scheme was devised to study the height/error variation thoroughly by means of special flights in which many of the variable factors, which may have tended to affect the validity of previous conclusions, ~~are~~ were to be controlled. Amongst these factors the following were the most important -

(a) The same set of crews ~~are~~ were to carry out all the necessary bombing.

(b) The division of effort with respect to height ~~is~~ was to be made even amongst all the crews taking part.

(c) The collection of results ~~is~~ was to be carefully supervised with a view to securing full data on all the bombs dropped.

/Windfinding

(1) A. Accuracy of Blind Ground Marking by P.F.F. H2S May to September 1944: Bomber Command O.R.S. Report No. S.200. (A.H.B./IIH/241/22/14).

Windfinding

When the O.R.S. began to take an active interest in practice bombing the two most frequently used types of winds used for bombing were the navigator's wind and the 'met' forecast wind both of which were liable to considerable random errors. The effect of these inaccurate winds was to increase the crew errors considerably and, moreover, in the case of very inaccurate winds the vector error was sufficiently great to convert an otherwise normally aimed bomb into a gross error. In addition to the necessity of a good bombing wind it is of paramount importance in bombing analysis to have a good wind for analysis purposes. A smoke-puff wind computed by the range party with a Hill's mirror (1) was the method laid down in the instructions. For a variety of reasons, however, smoke-puff winds were frequently not available. On such occasions the important step in bombing analysis of comparing the positions of the vector target and the M.P.I. of the bombs could not be carried out. An attempt was made to increase the number of smoke-puff winds taken but the difficulty of congestion on the range was, at times, insuperable.

Eventually an improved method of obtaining an analysis wind using the standard A.P.I. was devised and a full description of the method is given in the Bomber Command Armament Note Part IV. (2) This method was explained to the Senior Air Staff Officer of No. 5 Group by a member of O.R.S. Bomber Command and he agreed to give the method a month's trial in the group. It proved so successful that it was adopted as standard procedure in the group. Moreover, in the following month, this method was extended in No. 5 Group to find a bombing wind, a 15 minute orbit being carried out on an easily identifiable object in the vicinity of the bombing range, the A.P.I. being read at the commencement and the end of the orbit. The wind was calculated from the difference between the two readings and was used throughout the exercise. The effects of this new method of windfinding upon the overall accuracy of No. 5 Group's practice bombing figures was shown in an appendix to a Bomber Command O.R.S. Report ~~No. S.220~~ on the importance of windfinding. (3) Over the period concerned the mean effective average errors (converted to 20,000 feet) for the whole of No. 5 Group were as follows:- April 210 yards, May 220 yards, June 213 yards, July 170 yards and August 175 yards. This very marked improvement which was equivalent to a reduction of the windfinding error of about 7 miles per hour, was maintained in subsequent months. No. 5 Group claimed by the middle of 1945 to have reduced the windfinding error on practice bombing to an average figure of 3 miles per hour using the 15 minute A.P.I. orbit method.

/Another

(1) Hill's Mirror – a device used to project an image of a smoke puff on to a table and thus enable wind to be computed from the movement of the image.
(2) Bomber Cmd. Armament Training Notes, Part I, Bombing Serial No. 4.
(3) 'Bombing Accuracy with Mark XIV Bombsight.' Bomber Command O.R.S. Report No. S. 220. (A.H.B./IIH/241/22/14).

Another example of the value of this method was obtained in an analysis of the results of No. 4 Group's September practice bombing effort. During this month the No. 44 Base squadrons had been using the A.P.I. method of obtaining a bombing wind and the remainder of the group had been using other methods. Since, otherwise, all squadrons were bombing under similar conditions the circumstances were favourable for a test of the efficiency of the A.P.I. method. The overall 50 per cent error for No. 44 Base was 207 yards (905 bombs) compared with a figure of 267 yards (1020 bombs) for the rest of the group. It was presumed that most of this difference was due to more accurate windfinding. The A.P.I. method of obtaining winds both for analysis and bombing later became general in these Bomber Command squadrons which possessed the necessary equipment.

In the appendix on windfinding referred to above (1) a useful method of recording bombing winds was described and recommended for use at bases. The method was illustrated by three examples of A.P.I. winds found over a certain range on three particular days. It consisted of making a distribution of the winds in time and in height, the winds being represented in magnitude and direction by vectors. Where available the Met. Ballon Sonde wind was also inserted in the distribution as a dotted line the A.P.I. winds being represented by full lines. The effect of this arrangement of the wind data was to reveal the variations of windspeed and direction with time and height. It was obvious in certain cases that a particular wind vector differed so strongly with the trend in nearby cases that the reported bombing height must have been at fault. The usefulness of this method as a check on reported bombing heights as well as a record of bombing winds was stressed.

Causes of Gross Error

From the earliest attempts to analyse practice bombing results it was obvious that the errors must be divided into two separate and distinct categories i.e. normal and gross errors. Most of the analysis was confined to the normally aimed bombs and considerable progress was made with the systematic analysis of these errors. The gross errors, which amounted to approximately 20 per cent of all bombs dropped, were not studied so carefully, mainly because of lack of data on them (e.g. frequently the distance from the target was not known). Little was known of the precise causes of gross errors but it was thought that instrumental faults were probably the principal source of such errors. In

/April 1944

(1) 'Bombing Accuracy with Mark XIV Bombsight'. Bomber Command O.R.S. Report No. S.220. (A.H.B./IIH/241/22/14).

April 1944 an investigation into the causes of gross errors was carried out by the O.R.S.

The Training Branch had been rather disturbed by the increase in the number of irregular releases that were occurring on practice bombing ranges and they asked the O.R.S. to investigate the causes of them. (An irregularly released bomb is one which falls outside the danger area of a bombing range). Since such incidents are liable to cause public accidents full reports on them are submitted by units to Groups and by Groups to Air Ministry and Bomber Command. These reports give the magnitude of the bombing error and the unit Bombing Leader's explanation of its cause. The collected reports therefore formed a very good basis for investigation of the principal causes of these errors.

These irregular releases did not, of course, include all gross errors and, in fact, they constituted only a very small percentage of them. The errors analysed by the O.R.S. ranged in value from 500 yards to two and a half miles with one error of six miles, the mean height of dropping being 9,500 feet, whereas the usual boundary between normal and gross errors was in the region of 300 yards at this height. Moreover it is possible that the irregular releases did not represent even a typical sample of gross errors being confined to the larger values. However it was thought reasonable to suppose that the causes of the irregular releases would bear a fairly close resemblance to the causes of gross errors in general. It seemed, therefore, that the proposed investigation would fulfill the dual purpose of providing the Training Branch with a basis for remedial action on the subject of irregular releases and at the same time of filling a gap in the O.R.S.'s knowledge of the causes of practice bombing inaccuracy.

A total of 346 incidents which occurred in Nos. 6, 7, 91 and 92 Groups during January, February and March 1945 were analysed.(1) The causes of the incidents were divided into a number of appropirate headings and tabulated by causes, groups and months. The complete total of incidents due to each of the various causes was calculated. These totals were the most useful ones as the individual group and monthly totals were too small to yield significant conclusions although some of the more obvious inter-group comparisons were pointed out.

It was found that the two most frequent causes of irregular releases were air bomber faults (principally 'incorrect line of sight', 'failure to carry out correct levelling procedure' and, sic, 'poor bombing') and bombsight faults which together amounted to rather more than 50 per cent of the total.

Faults due directly to various members of the aircrew (i.e. pilot, navigator and airbomber) together amounted to 35 per cent

(1) 'Causes of Irregular Release with the Mark XIV Bombsight in Practice Bombing.' Bomber Command O.R.S. Report No. S.219. (A.H.B./IIH/241/22/14).

35 per cent of the total. Since 10.6 per cent were due to weather and may be considered as unavoidable and 13.1 per cent were not classified it was obvious that far more gross errors than had been imagined were due to manipulative errors. In designing the new categorisation scheme for practice bombing which is described later in this chapter this fact influenced the decision to include gross errors in each exercise score.

The errors of the bombsight were broken down into smaller categories based on its separate functions and the principal source of large errors within the bombsight were found to be poor suction and faulty gyros which amounted to five per cent of the total.

The report provided a basis for action by the Training Branch in a drive to reduce the frequency of irregular releases.(1)

Operational Training Unit Bombing

By the beginning of 1945 the accuracy of bombing by fully trained crews using a vector bombsight had been thoroughly investigated by the O.R.S. Standardised methods of bombing analysis had been introduced and these had been of value in raising the quality of bombing accuracy throughout the operational groups. When the investigation into bombing accuracy was begun a number of operational training unit bombing results were received by the O.R.S. At this time operational training units were not equipped with complete Mark XIV bombsights and were bombing with sighting heads only. A superficial analysis of these results showed them to be somewhat better than current operational squadron practice figures. However, it was not thought worthwhile to carry out an extensive analysis of operational training unit bombing until the complete Mark XIV bombsight was being used by operational training unit crews.

In January 1945 an investigation into operational training unit bombing was made by the O.R.S., the bombing records of twelve crews from No. 24 Operational Training Unit, Honeybone being used as the source of bombing data.(2) Added interest was lent to the investigation by the fact that the T.1 bombsight (i.e. the American version of the Mark XIV) was used by the operational training units though it was not anticipated that any conclusions concerning the bombsight would be reached on the strength of this analysis.

The method of analysis was similar to that used for the operational group results. The bombing effort was divided into height bands and into the usual error intervals, i.e. less than

/100.

(1) 'Causes of Irregular Release with the Mark XIV Bombsight in Practice Bombing.' Bomber Command O.R.S. Report No. S.219. (A.H.B./IIH/241/22/14).

(2) 'Accuracy of Bombing by O.T.U. crews using T.1. Bombsight' Bomber Command O.R.S. Memo. No. M.16. (A.H.B./IIH/241/22/3)

100, 141, 200, 282 and 400 yards. For each height band an effective average error and a gross error percentage were quoted. An overall converted accuracy figure of 267 yards at 20,000 feet was obtained. This was significantly worse than the current operational squadron figures and it was suggested that the difference was large due to the more accurate windfinding techniques in use in the squadrons.

The sample of bombs analysed consisted of almost exactly equal night and day figures. The accuracy achieved on night and day bombing was compared and the night accuracy was found to be significantly better than day accuracy (effective average errors at 20,000 feet were 247 yards and 278 yards respectively). No such significant differences had been observed from the results of operational squadrons. It was suggested that the illuminated target and lack of other distractions in the vicinity of the target might be the operative factors in the case of operational training unit crews. Another noteworthy result was that the gross error percentages lay between two per cent and four per cent, much lower figures than were obtained on squadrons.

In spite of the smallness of the sample of the bombs an attempt was made to measure the height/error variation by the method described in the section dealing with the height/error investigations. The index obtained was 0.22, a very low figure, indicating that for this sample of results the accuracy did not fall off so rapidly with increase of height as it did normally in the operational groups; but due to the smallness of the sample no significance could be attached to the results.

Despite these interesting differences which might have repaid further investigation no more work was done on operational training unit analysis by the O.R.S.

Crew Categorisation

In the latter half of 1944 an attempt was made by No. 5 Group and afterwards by other groups to categorise crews in terms of their practice bombing accuracy. Generally speaking the two main reasons for these attempts were:-

(a) To establish an approximate order of merit amongst crews with a view to selecting the best ones for key jobs such as marking and 'backing-up' on operations.

(b) To stimulate interest in practice bombing by providing crews with a reasonable tangible degree of improvement to aim at.

In February 1945 an instruction of the subject of crew categorisation was issued by the Training Branch of Bomber Command; the purpose of the instruction was to standarise the categorisation of crews throughout the Command and it defined the method of procedure to be adopted at the operational training unit, heavy conversion unit and operational stages.

/The

The method laid down was extremely simple. It consisted merely of taking the average of the crew errors on the three most recent exercises converted to 20,000 feet and categorising according to the following criteria:-

Category A	Errors up to 120 yards.
Category B	Errors between 121 yards and 200 yards.
Category C	Errors between 201 yards and 280 yards.
Category D	Errors greater than 280 yards.

At the same time the O.R.S. was asked to initiate an investigation into the working of this scheme and to assess its value. It seemed likely that it would be most difficult to estimate the usefulness of the scheme in so far as heading (b) above was concerned and that the opinion of bombing leaders and others connected with the active employment of the method would have to be accepted. Although there were some serious and fundamental objections to the method on purely theoretical grounds it was decided to carry out an investigation into the actual operation of the method in practice, and into the extent to which it answered the requirement stated under heading (a) above.

O.R.S. representatives visited Nos. 4, 5 and 7 Groups and collected a considerable quantity of data on the practice bombing history of a number of crews. This data was in the form of the results of all the practice bombing exercises carried out by the crews concerned during their careers with the Groups. The average crew error and converted crew error as calculated by the Groups was also recorded.

The first stage of the analysis was to re-compute the average crew errors and to conver these averages to 20,000 feet. A comparison of these figures as calculated by the O.R.S. with the group figures revealed some remarkable differences. It was found that nearly 20 per cent of the converted averages as obtained from the groups had errors exceeding ten yards and that there was a distinct negative bias attached to these errors (nearly 15 per cent of the errors over ten yards were negative i.e. less than the correct value).

The corrected converted averages were then grouped in threes and the averages of these sets of three (i.e. the measure used to determine category) were calculated for all the available crews. A histogram illustrating the frequency distribution of these averages of sets of three was drawn and a normal curve was fitted to the results. The following percentage frequencies of occurrence of categories was found:-

/Category A

Category A	0 - 120 yards	2.1%
Category B	120 - 200 yards	51.5%
Category C	201 - 280 yards	37.5%
Category D	Over 281 yards	8.9%

It seemed obvious that such a distribution of categories was unnecessarily coarse and, while it was probably a sound idea to have a small 'expert' class the division of all crews into, effectively, two categories results in little better than an 'above and below average' classification. Further research into this method of categorisation seemed likely to be unfruitful and so the O.R.S. summarised its comments on it and devised an alternative categorisation scheme specifically designed to cover the criticism made of the original method.(1) The main criticisms were:-

(a) No account was taken of gross errors.

(b) No credit was given for chronological improvement.

(c) No account is taken of fluctuation from exercise to exercise or, in other words, no credit was given for consistency.

(d) The category boundaries were arranged in such a way that the distribution of the crews between categories was unequal and unsystematic.

(e) The percentage of serious mistakes (mistakes greater than ten yards) made by bombing analysis officers in deriving the average crew error and in converting it to 20,000 feet was nearly 20 per cent. (It should be noted, however, that this was not a criticism of the method but of its application).

The proposed new system gave to each crew a score based upon three separate factors, i.e. (1) the value of the mean radial average value per exercise (ii) the degree of fluctuation between exercises (iii) the rate of imrpovement. Gross errors were accounted for by giving a fixed value of 400 yards at 20,000 feet to all converted errors of over 400 yards.

Five exercises were deemed necessary for categorisation and the procedure was, briefly, as follows. Converted average radial error (Y axis) was plotted against exercise value (X axis) for the first to the fifth exercise and the regression line of average radial error on exercise value was drawn. The slope of this regression line (in yards per exercise) was taken as the factor of improvement. The average of the differences between each average radial radial errors and the values of the Y ordinate of the regression line at the corresponding points was taken at the fluctuation factor. This factor corresponded to the

/average

(1) 'A Suggested New Method for the Calculation of the Practice Bombing Categories of Crews.' Bomber Command O.R.S. Report No. 139. (A.H.B./IIH/258/3/9).

average difference between actual results and expected results the latter being taken as lying on the regression line. The mean of the five average radial errors was the third factor.

These calculations were performed on 93 sets of five successive exercises taken from the Nos. 4, 5, and 7 Group sample mentioned above and frequency distributions of improvement, fluctuation and mean factors were constructed. After a close examination of the mean and standard deviation of each of these distributions it was decided that each of the three factors must be given unit weight in the score if anomalies were to be avoided.

On this basis the scores for the 93 cases were calculated and expressed in the form of a frequency distribution. This distribution was then divided up into suitable bands for categorising the scores, the basis being that categories A and D should each comprise One sixth of the total and Categories B and C should each have one third of the total. The resulting boundaries were:-

Category A	less than 245 yards
Category B	246 - 295 yards.
Category C	296 - 320 yards.
Category D	greater than 320 yards.

The provisional nature of this grouping and the necessity of checking it with further data were stressed.

The possible application of this method to a wider sphere of training activities was mentioned briefly in the report.(1) The new scheme received the provisional approval of Training Branch at Bomber Command in August 1945 and the report on it was published with a covering letter from them asking groups and other formations for their comments on it.

Improvement with Practice of Crews using the Mark XIV Bombsight

Although it is obvious that there is a considerable improvement in the accuracy of a crew's bombing from the operational training unit to the operational stage there was some doubt as to whether operational crews continued to improve during their careers on squadrons. An opportunity to investigate this problem arose out of the analysis of categorisation scores.(2)

A large quantity of data had been collected from groups covering the practice bombing histories of about ninety crews. These data were divided into two sets, one covering a number of crews through the heavy conversion unit stage (No. 7 Group) through to the operational stage (No. 5 Group) and the other set covering a number of No. 4 Group crews, most of whom had completed at least one

/operational

(1) 'A Suggested New Method for the Calculation of the Practice Bombing Categories of Crews.' Bomber Command O.R.S. Report No. 139. (A.H.B./IIH/258/5/9).

(2) 'The Effect of Practice on Bombing Accuracy.' Bomber Command O.R.S. Report No. S.225. (A.H.B./IIH/241/22/14).

tour. The two sets were analysed separately and since errors from the target only were available the analysis was, of course, confined to crew errors.

All bombing errors were converted to 20,000 feet and those which were greater than 400 yards when converted were rejected as gross errors; the average of the remaining errors for each exercise was taken as the mean radial error for the exercise concerned. Then the average of all mean radial errors of all first exercises, all second exercises etc. were calculated. This gave, in effect, a series of measures of the average accuracy (i.e. overall mean radial error) achieved on successive exercises. These measures were plotted out separately for the two sets of data with overall mean radial error as the Y axis and exercise number as the X axis. A marked downward trend was noticeable in both graphs indicating systematic improvement with practice. Although such improvement cannot continue indefinitely it was thought reasonable to fit regression lines (i.e. regression of overall mean radial error on exercise number) to the data, provided that no attempt was made to extrapolate the regression lines beyond the limits of the data used. The slopes of these regression lines were regarded as measuring the systematic trend of the results and they showed improvement of five yards per exercise (over 12 exercises) for No. 4 Group crews and three yards per exercise (over 11 exercises) for Nos. 5 and 7 Group crews. The greater improvement rate for No. 4 Group crews is partly explained by the much higher initial results in the case of No. 4 Group (compare Y coordinates in each case when X = 0: No. 4 Group 221 yards and 7 Group 181 yards) which afforded them greater scope for improvement.

It was thus established that amongst operational crews practice bombing accuracy continued to improve at least up to the twelfth exercise and as few crews performed as many as twelve exercises further practice bombing was likely to be profitable. It was, unfortunately, impossible to examine the data to find out how much of the improvement was due to bombing, flying and wind-finding improvements because bomb-fall plots and wind-finding data were not available.

An investigation into the alteration of frequency of occurrence of gross errors with practice was carried out using a method similar to that described for the mean radial errors. A small decrease of gross error percentage with the practice was revealed but the result was not statistically significant.

/Practice bombing .....

Practice bombing Accuracy with the Stabilised Automatic Bombsight Mark IIA

The estimation of bombing accuracy achieved on practice with the stabilised automatic bombsight was never such a difficult problem as the assessment of Mark XIV results. The sight was in use in one squadron only, i.e. No. 617 Squadron and the quantity of practice bombing results was small and correspondingly manageable. Moreover the results were received regularly by the O.R.S. in the form of teleprinter signals direct from the bombing range. A detailed investigation was made into the practice results achieved by No. 617 Squadron during the period from March to October 1944 and the results of this investigation were published in December 1944.(1)

The total sample of bombing errors available for analysis consisted of more than a thousand bombs. These were subdivided into 2000 feet height bands and into five periods i.e. March-April, June-mid-July, mid-July-August, September and October, each of the periods containing approximately 200 bombs.

The average error for each height band and each period was calculated. In the calculation of these averages, errors over 400 yards which amounted to between two per cent and three per cent of the total, were omitted and counted as gross errors. The overall average error was about 100 yards and the mean height of dropping was approximately 12000 feet; the average error was remarkably constant throughout the eight months period. The average error achieved on practice was slightly poorer than the service trial figure of 110 yards for the height band 17,000-21,000 feet.

The variation of accuracy with height was examined and although the results up to mid-July showed no significant variation there was a significant decrease in accuracy with height during the last three months of the period.

The most important observations were made from a set of plots of bombs on line and range axes. These plots were based upon the September and October results and were for heights of 8,000, 10,000 and 12,000 feet. They revealed a very marked, significant overshoot of 33 yards at 8,000 feet, eight yards at 10,000 feet and 12 yards at 12,000 feet. There was also a small systematic port tendency which was not significant. Moreover the random errors were much greater across in line than in range, the ratio of the line to range standard deviations being 1.4.

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(1) 'Accuracy of Bombing with S.A.B.S. Mark IIA.' Bomber Command O.R.S. Report No. S.190. (A.H.B./IIH/241/22/14).

The following recommendations were made -

' (a) Crews should be made aware that their tracking errors are worse than their range errors and, therefore, rather more attention must be paid to them.

(b) An allowance should be made for the overshoot. An immediate approximate cure would be to use a different terminal velocity scale.

(c) In view of the uncertainties of the ballistics of practice bombs at high altitudes it is suggested that some practice is done with 250 pound general purpose bombs which have well established and good ballistics to check the presence or absence of a systematic overshoot.'

A similar analysis to that described above was again carried out in April 1945 on the data for the proceeding three months. The average error was slightly poorer than before being 113 yards for a mean height of dropping of 12,000 feet. There was again a small systematic overshoot but it was not significant and the random range and line errors were almost exactly equal.

CHAPTER 11

GEE AS AN AID TO BLIND BOMBING

The Gee Principle

The navigational equipment known as Gee was based on the use of three ground stations, arranged approximately equidistantly and nearly in a straight line, emitting synchronised pulses of high frequency radio energy (20 - 70 Megacycles per second). The central station, called the 'master', emitted pulses which were used to trigger off the outer stations, called 'slave' stations, after suitable phasing adjustments had been made. The signals from all three stations were received and displayed on a cathode ray tube equipment in the aircraft. This equipment was designed to measure the time interval between the receipt of signals from the master and each of the slaves. Considering the master station and one slave, it will be seen that for a given time difference between the receipt of signals from each of the two stations an infinite number of positions for the aircraft receiver were possible, all of which lay on a hyperbola having the ground stations as foci. Further, all possible time differences would be represented by a family of confocal hyperbolae. Similarly, due to the master and the other slave, a second family of hyperbolae would be generated which would intersect the first family. These hyperbolae could be drawn on a 'lattice chart' which was carried in the aircraft. All that was necessary for the navigator to do was to measure the time delays using his Gee equipment, or TR1335 as it was originally called, and to identify the appropriate hyperbolae on his chart. The point of intersection of the hyperbolae gave a fix, the accuracy of which was a variable dependent on the position of the aircraft with respect to the ground stations and the accuracy with which the measurements were made.

The Early Development and Trials of Gee

The first experimental Gee receiver was flown on 19 October 1940, using a two station chain. Trials were carried out to measure position lines and successful attempts were made to home along pre-calculated hyperbolic paths. These flights showed that the basic principles were sound but that more technical development was required before large scale manufacture could be

/considered.

considered. Flight trials of a more highly developed Gee receiver and indicator were made on 27 December 1940, and this new equipment proved much more successful. In the meantime, work had been going on to produce the Mark I Gee airborne equipment and a high power transmitter for use as a ground station. By 15 May 1941 this work had been successfully completed and flight trials showed that the equipment was quite satisfactory and that ranges of the order of 400 miles at 10,000 feet could be expected. Work was immediately begun on six airborne equipments which were installed in Wellington aircraft of No. 115 Squadron at Marham for service trials. These service trials, with which the O.R.S. was closely associated, were carried on for a period of two months. It was concluded that Gee was far in advance of any other navigational equipment in the R.A.F., and that it was extremely simple to operate.

The first Gee chain to be set up was the 'Eastern Chain'. With the master station sited at Daventry and the slaves at Stenigot and Gibbet Hill, it gave the maximum possible accuracy over the Ruhr, where a large number of high priority targets were located and which was just within range of the system. Whilst carrying out trials on this chain over Germany on 11 August 1941, one of the aircraft of No. 115 Squadron unfortunately failed to return. It was very important to determine whether the equipment was likely to have fallen into enemy hands in a relatively undamaged state, and the O.R.S. was asked to investigate the available evidence regarding the causes of the loss of all the aircraft missing on that night. It was concluded that all or nearly all the aircraft which were missing had either crashed in flames or exploded in the air, and that it was therefore unlikely that the Gee set had fallen into the hands of the enemy. (1)

The potentialities of Gee seemed so great that Bomber Command wanted it as soon as possible in large numbers. In order to ease the production problem the O.R.S. suggested a modification to the Gee system which might have reduced the number of valves in the equipment and so speed up production. (2)

/The

(1) 'Investigation into the loss of a Gee aircraft.' Bomber Command O.R.S. Report No. S.2.

(2) 'Suggested Modification to Gee Systems.' Bomber Command O.R.S. Report No. S.1.

The principle of estimating positions by measuring the differences between the time of arrival of signals from three ground stations was retained, but, instead of using a micro-clock consisting of electrical circuits and employing numerous valves, it was proposed to use a stop watch assisted by a 'time transformer' working on a stroboscopic principle and controlled from the ground. However, it was decided that in the long run it would be better to proceed as originally planned.

It had been suggested in certain quarters that for security reasons it might not be possible to allow navigators to take with them over enemy territory a Gee lattice chart which would reveal the sites of the ground stations. It was therefore decided to carry out an investigation to determine the practicability of using the system with certain numerical data instead of charts. Navigators were actually supplied with the lattice co-ordinates of the target and two or three known positions en route. It was shown conclusively, however, that the great advantages of Gee would be almost entirely lost if navigators were unable to refer to a chart, since not only was it necessary to know certain co-ordinates but also the spacing and direction of the lattice lines.

Research into the Operational Techniques to be used with Gee

By the end of 1941 it was clear that Gee would be available for use in operations against the enemy in the near future. It was thought at this time that the major problem confronting Bomber Command crews was that of target identification since it was considered that dead reckoning navigation was sufficiently accurate to ensure that in the majority of cases aircraft arrived within about 20 to 30 miles of their targets. It was considered that with Gee much more accurate navigation would be possible and much thought was given by the various branches at Bomber Command to the possibility of devising a method of using Gee as an aid to target location. In December 1941, the O.R.S. produced a report outlining some of the possible ways of using Gee.(1) The facilities directly provided by Gee were first discussed, e.g. accurate fixing and homing. The report then went on to discuss the

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(1) "Operational Use of Gee." Bomber Command O.R.S. Report No. S.23.

operational facilities which would be provided, e.g. navigation to near the target, homing to a target, wind determination and blind bombing, and indicated the various tactical uses for the equipment, such as timing of operations and routeing of aircraft etc. Finally, it was suggested that in view of the short life which could be expected from Gee, because of the probability of enemy jamming, it was very desirable to carry out some trials to determine how Gee could be best employed. The service trials, it was pointed out, showed that Gee worked very satisfactorily but did not point out the best way to apply the equipment in the bomber force as a whole. These suggested uses of Gee, and in particular the recommendation for service trials, were approved by the Air Staff and a programme of experiments was drawn up by the O.R.S. in consultation with the Group Captain Operations, Chief Signals Officer and Chief Navigation Officer. These experiments ~~which were given in Bomber Command O.R.S. Report No. S.26 (1)~~ were divided into two main sections (a) accuracy trials, and (b) trials of operational techniques.(1) The Gee Development Flight, later to become No.1418 Flight and finally the Bombing Development Unit, was formed to carry out these trials. The result of the accuracy trials were presented in a report by the Air Warfare Analysis Section (Report No. BRA3), who had been responsible for the preparation of the charts. It was concluded that the random errors of observation amounted to 0.0115 of a Gee unit (standard deviation) and that there was no systematic error over Galloway, the region where the trials were carried out.

A conference was held at Headquarters Bomber Command on 17 January 1942, under the chairmanship of the Commander-in-Chief, to discuss the operational use of Gee. The agenda for this was drawn up by the O.R.S. At the conference it was decided that Gee-fitted aircraft could only be used by themselves when conditions were such that only blind bombing was possible, on all other occasions Gee aircraft could be used to lead the main force on to the target. It was agreed that only two methods of leading the main force on to the target could be used, (a) by Gee aircraft dropping incendiaries blindly and the main force bombing the fires, or (b) by Gee aircraft

/illuminating

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(1) 'Operational Use of Gee II'. Bomber Command O.R.S. Report No. S.26. (A.H.B./II/69/210).

illuminating the target with flares. An alternative suggestion that non-Gee aircraft should fly in formation with Gee aircraft was considered impracticable for night operations. In view of the uncertainty of the technique of operation to be carried out by the follower and leader aircraft in the flare method, it was decided that trials should be carried out under conditions comparable to those over the Ruhr, as soon as the accuracy trials were completed. To implement this decision the O.R.S. wrote a paper ~~on 'The Use of Flares in Conjunction with Gee', (1)~~ outlining the proposed experiment which was given the code name Crackers and was carried out by No. 3 Group.(1) Selby railway station on the Isle of Man was selected as the target, since the Gee lattice lines were similar to those over the Ruhr. The experiment was carried out on the night of 13 February 1942, and at a conference held at No. 3 Group on 15 February 1942, at which several O.R.S. representatives were present, it was decided that the experiment must be considered a failure due to a technical breakdown. However, valuable experience was gained which was used when the outline of Crackers II was drawn up. This was carried out on the night of 19 February 1942 using Brynkir (North Wales) railway station as a target. This experiment was much more successful, and No. 3 Group were able to make recommendations on the use of a flare technique suitable for actual operations. In this type of operation, which came to be known by the code name Shaker, the general idea was that selected crews should drop flares blindly on Gee over the centre of the target at the beginning of the attack. Provided enough crews were detailed for this duty it was considered that the area so illuminated would include the aiming point in spite of the relative inaccuracy of the fixes obtainable at long range. Other specially selected crews were then to search for the aiming point in the light of the flares, and bomb it with incendiary bombs. The remainder of the force would then bomb the fires so created. The operation was, of course, dependent on clear weather. Under cloudy conditions blind bombing attacks on Gee could be used and were designated Samson attacks. It is of interest to note how closely these original proposals by the O.R.S. for the use of Gee were followed in the techniques that were adopted later for the Pathfinder Force.

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(1) 'The Operational Use of Gee III. The Use of Flares in conjunction with Gee.' Bomber Command O.R.S. Report No. S. 30.

The Results Obtained by Gee in Operations

The first Gee operation took place on the night of 8/9 March 1942 using the Shaker technique. Flares were dropped blindly on Gee to illuminate the target which was a marshalling yard south-east of Krupps in the old town of Essen. An incendiary force followed with instructions to navigate to the target area using Gee, and then to identify and bomb the target in the light of the flares. The main striking force was then to bomb the fires which it was hoped would be large enough to make the target unmistakable. From an analysis of the operation carried out by the ORS.[1] there is little doubt that the majority of Gee aircraft passed close to the target and built up areas were sighted and bombed but, unfortunately, these were not always Essen. However, having regard to the fact that it was the first operation, it was considered that the results were encouraging and provided valuable lessons both for the aircrew and planning staff. A report on the technical performance of Gee[2] was also written about this operation, and this and other similar reports are discussed later in this chapter.

The attack on Essen was followed by a second and more successful one on the next night, using the same technique. The third attack on Essen on 10/11 March 1942 was, however, carried out without the use of flares. The target was blind-bombed by Gee using incendiary bombs, the fires caused by these bombs were then to be attacked by the main force. Photographic evidence showed that little success was achieved by the main force due to the small concentration in time achieved at the target by the Gee aircraft together with the small and quite insufficient illumination produced by the 250 pound incendiary bombs. These attacks were also reported on in Report Nos. B.102[3] and B.103.[4]

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(1) 'Attack on Essen 8/9 March 1942 using T.R.1335'. Bomber Command O.R.S. Report No. B.101. (A.H.B./IIH/241/22/12)
(2) 'Report on Performance of T.R.1335 and Stations Type 7000. Attack on Essen 8/9 March 1942.' Bomber Command O.R.S. Report No. S.35. (A.H.B./IIH/241/10/89).
(3) 'Attack on Essen 9/10 March 1942.' Bomber Command O.R.S. Report No. B.102. (A.H.B./IIH/241/22/12).
(4) 'Attack on Essen 10/11 March 1942.' Bomber Command O.R.S. Report No. B.103. (A.H.B./IIH/241/22/12).

Other Gee attacks of interest were on Kiel 12/13 March 1942,(1) Cologne 13/14 March 1942,(2) Essen 25/26 March 1942,(3) Cologne 5/6 ~~[illegible]~~ March 1942,(4) Essen 12/13 April 1942,(5) Cologne 27/28 April 1942 (6), Bremen 2/3 July 1942,(7) and Duisburg 21/22 July 1942.(8) Most of these attacks were carried out using either Shaker or modified Shaker techniques.

An attack of particular interest was that on Cologne on 22/23 April 1942, when some 80 aircraft were detailed to blind bomb the city on Gee. Night photographs were to be taken for the purpose of analysis. Unfortunately, however, the evidence obtained was inconclusive and the degree of success of the raid could not be accurately assessed. Such evidence as was available, however, appeared to indicate that the attack was scattered over an area round Cologne and within 5 to 10 miles of it, and that in all probability only a small proportion of the bombs dropped actually fell in Cologne itself.(9) ~~(Report No. S.44 refers). (9)~~ In view of the importance of determining the accuracy of blind-bombing by Gee, the O.R.S. analysed the available evidence from all operations in an attempt to get a broad picture of the operational accuracy of this method of bombing. The results are given in a Bomber Command O.R.S. Report,(10) ~~No. S.47. (10)~~ which concluded from the evidence available that when operational crews blind-bombed heavily defended targets in the Ruhr and Rhineland the accuracy obtained was more than three times worse than that obtained by expert crews of No. 1418 Flight over this country. In particular it was estimated that in a blind attack on Essen 5 to 10 per cent of all bombs dropped would fall in the town and about 2 to 3 per cent in Krupps works. A memorandum was prepared on the ten raids which had been carried out on Essen up to the end of May 1942.(11) ~~(Report No. B.111) (11)~~ The evidence from these operations was examined, and it was concluded that the best results were likely to be achieved by

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(1) Bomber Command O.R.S. Report No. B.104. (A.H.B./IIH/241/22/12).
(2) Bomber Command O.R.S. Report No. B.105. (A.H.B./IIH/241/22/12).
(3) Bomber Command O.R.S. Report No. B.107. (A.H.B./IIH/241/22/12).
(4) Bomber Command O.R.S. Report No. B.108. (A.H.B./IIH/241/22/12).
(5) Bomber Command O.R.S. Report No. B.109. (A.H.B./IIH/241/22/12).
(6) Bomber Command O.R.S. Report No. B.110. (A.H.B./IIH/241/22/12).
(7) Bomber Command O.R.S. Report No. B.112. (A.H.B./IIH/241/22/12).
(8) Bomber Command O.R.S. Report No. B.114. (A.H.B./IIH/241/22/12).
(9) 'Blind Bombing Attack on Cologne, 22/23 April 1942.' Bomber Command O.R.S. Report No. S.44. (A.H.B./II/39/1/2).
(10) 'Operational Accuracy of Blind Bombing with T.R. 1335, March-April 1942.' Bomber Command O.R.S. Report No. S.47. (A.H.B./II/69/157).
(11) 'Attack on Essen. Blind Bombing by T.R. 1335.' Bomber Command O.R.S. Report No. B.111. (A.H.B./IIH/241/22/12).

blind bombing attacks in view of the difficulties of visual identification of the target through the Ruhr haze.

Concurrently with these intensive investigations into the operational performance of Gee, the O.R.S. was engaged on investigations into the accuracy with which fixing and homing could be carried out. In particular, attention was paid to the reduction and possible elimination of systematic errors introduced by the slave station operators attempting to maintain accurate phasing, and to the monitor stations ability to detect the correctness or otherwise of the phasing delays actually applied at the slaves. The disappointing operational results obtained with Gee led to a concentration of effort to reduce both these errors introduced on the ground and those introduced in the air. Much of this work was purely technical and is discussed in detail in a later section of this chapter, but it was clear that every available opportunity for training crews in the homing technique would have to be seized if the maximum improvement in the operational results was to be obtained. Since practice flights carried out by operational squadrons could provide much data valuable both to the crews and to planning staffs, if the flights were properly organised, the O.R.S. wrote ~~Report No. S.56 (1)~~ a report on how these could best be carried out.[1] The report described the kind of flights which should be carried out and gave a list of suitable areas for them. Micro-lattices were drawn up for these areas, and it was then easily possible to check the position of ground photographs against Gee fixes. It was arranged for all the data, photographs etc., to be sent to the O.R.S. and a return-of-post system was organised whereby crews were told with the minimum of delay what their errors were.

In view of the failure of Gee as a blind bombing device which it was, of course, never intended to be, a second memorandum was written on the attacks on Essen with a view to analysing the causes of the poor results. This was finally published as a Bomber Command Air Staff Note, dated 26 July 1942. It was concluded that although blind bombing on Gee would

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(1) '~~Proposals for T.R.1335~~. Trial Flights by Operational Squadrons.' Bomber Command O.R.S. Report No. S.56. (A.H.B./IIH/241/10/89).

not 'blitz' Essen, it was likely to achieve better results than any other method. Various other ways of achieving success were suggested, i.e. firstly improvements on the present techniques using extreme concentration of aircraft and special preparation of the crews, secondly use of a nearby landmark from which aircraft could make timed runs, thirdly blind bombing using an expanded time base on the navigators' indicator and special phasing of the ground stations[1] ~~(Bomber Command O.R.S. Report No. S.35) (1)~~ and the use of marker bombs and selected target marking aircraft.

The operational Performance of the Gee Equipment

One of the functions of an O.R.S. is to analyse the performance of new devices as they are brought into service. Accordingly, a pro-forma was devised, in conjunction with the Radar Branch of Bomber Command, which could readily be filled by crews returning from operations, and at the same time give sufficient data in the best available form for analysis. The pro-forma was designed to allow as many questions as possible to be answered merely by placing a tick in the appropriate space, and it was divided into three main sections with the following headings (a) Technical, (b) Navigational, and (c) Target. Each of these sections was sub-divided into a number of sub-divisions dealing with the ranges at which the signals faded, data dealing with found winds, and data dealing with the way the target was identified and bombed etc. The information obtained from these pro forma formed the basis of Bomber Command O.R.S. Reports Nos. S.35,[2] S.36[3] S.37,[4] S.38[5] S.39[6] and S.40,[7] each of which dealt with a particular night's operation. When the technical performance of the system became more stabilised these reports were discontinued and only published when there was something of definite interest. Reports in this category include (a) unusual low range of stations Type 7,000[8] ~~(No. S.42) (8)~~ and (b) range and operational performance of Gee in raids on Stuttgart.[9] ~~(Bomber Command O.R.S. Report S.49.) (9)~~ The point of interest of the first report is obvious, whilst that of the second was that Stuttgart was well outside Gee cover, which could therefore be used for only part of the flight. An omnibus

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(1) 'Accuracy of T.R. 1335 – Observational Errors.' Bomber Command O.R.S. Report No. S.55. (A.H.B./IIH/241/10/89).

(2) 'Report on Performance of T.R. 1335 and Stations Type 7000: Attack on Essen, 8/9 March 1942.' (A.H.B./IIH/241/10/89).

(3) 'Report on Performance of T.R. 1335 and Stations Type 7000. Attack on Essen, 9/10 March 1942.' (A.H.B./II/69/157).

(4) 'Report on Performance of T.R. 1335 and Stations Type 7000. Attack on Essen, 10/11 March 1942.' (A.H.B./II/69/157).

(5) 'Report on Performance of T.R. 1335 and Stations Type 7000. Attack on Kiel, 12/13 March 1942.' (A.H.B./II/69/157).

(6) 'Report on Performance of T.R. 1335 and Stations Type 7000. Attack on Cologne, 13/14 March 1942.' (A.H.B./II/69/157).

(7) 'Report on Performance of T.R. 1335 and Stations Type 7000. Attack on Essen, 25/26 March 1942.' (A.H.B./II/69/157).

(8) 'Report on Unusual Low Range of Stations Type 7000, Day 31 March 1942.' Bomber Command O.R.S. Report No. S.42. (A.H.B./IIH/[illegible]).

(9) [illegible]

report ~~No. S.52~~ was written which summed up the evidence on the range of Gee over the period 8 March 1942 to ~~20~~ 8 May 1942.(1)

Enemy interference with Gee was first encountered in August 1942 when various reports of 'lost signals due to much grass' were received from navigators. ~~Bomber Command O.R.S. Report No. S.60~~ ~~summed up the~~ Information to hand at the time and ~~gave~~ an account of certain investigations which were carried out by the Bombing Development Unit was reported on by the O.R.S.(2). It was concluded that Gee had been effectively jammed over Germany by means of modulated C.W. signals, and that the range from Daventry (the site of the Master station) had been reduced from about 400 miles to 250 - 300 miles. A report was written by the Bombing Development Unit on a flight carried out over Germany on 17/18 August 1942 to test an anti-jamming circuit. This report was included as an appendix to Bomber Command O.R.S. Report No. S.61 (3) dealing with the interference experienced up to 19 August 1942. Experience of latter raids confirmed the interference on earlier ones, and the report stated that the anti-jamming circuits showed great promise. A number of Gee sets were fitted with the anti-jamming modification and by 25 August 1942 three more attacks had been carried out. The O.R.S. analysed the data collected on these attacks ~~in Bomber Command O.R.S. Report No. S.62~~ and it was concluded that the modification was a successful countermeasure to the enemy jamming effort.(4) Bomber Command O.R.S. Report No. S.63 (5) dealt with three more attacks which took place at the end of September, and it was noted that the enemy appeared to be experimenting with a new type of jamming in the form of locked and unlocked pulses.

Beginning in September 1942, a careful analysis was made of the ranges obtained using Gee, and the O.R.S. published a series of tables known as 'Range Analysis Tables'. Copies of these were sent to groups and distributed down to squadrons, and it was possible for any squadron to compare its results with all the others. Bomber Command O.R.S. Report No. S.69 reviewed (6) the range of Gee since the start of enemy jamming in early

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(1) 'The Range of the 7100 (Eastern) Chain and T.R. 1335, 8 March to 8 May 1942'. Bomber Command O.R.S. Report No. S.52. (A.H.B./IIH/251/3/12 A).
(2) 'Gee Interference to 11/12 August 1942.' Bomber Command O.R.S. Report No. S.60. (A.H.B./II/69/210).
(3) 'Final Report on Gee Interference to 19 August 1942.' Bomber Command O.R.S. Report No. S.61. (A.H.B./II/69/210).
(4) 'Gee Interference 20/21 August 1942'. Bomber Command O.R.S. Report No. S.62. (A.H.B./II/69/210).
(5) 'Gee Interference and Countermeasures, 28 August to 23 September 1942'. Bomber Command O.R.S. Report No. S.63. (A.H.B./II/69/210).
(6) 'Review of the Operational Range of Gee, 2 July to 21 November 1942'. Bomber Command O.R.S. Report No. S.69. (A.H.B./II/69/210).

August, and compared it with the ranges obtained prior to the jamming. It was shown that the range fell sharply when jamming was first experienced, and that after a recovery brought about by the use of countermeasures the the range decreased again. This was possibly due to increased effort on the part of the enemy or possibly to the change in climatic conditions. A supplement to this report showed that up to December 1942 the decline in Gee ranges continued until 31 December 1942, when the range was only 280 miles. At the same time the Southern Gee chain, in an unjammed state, was giving ranges of the order of 400 miles. The Range Analysis Tables proved of value to various sections in T.R.E. which used them to carry out investigations connected with the effect of enemy jamming and propagation conditions on Gee ranges (T.R.E. Reports T1339 and T1496).

This work by the O.R.S. and T.R.E. was continued in 1943 when a series of monthly reports was written on the operational ranges obtained with Gee (Bomber Command O.R.S. Report Nos. S.86,[1] S.85,[2] S.87 [3] and S.93[4]) It was shown that enemy jamming was increasing in severity and that the Mark II receiver which had been introduced was showing little promise of materially increasing the ranges obtained.

Suggestions were made in various quarters that the effectiveness of enemy jamming could be reduced, even within the existing frequency band, by the introduction of decoy transmissions and other means of misleading the enemy as to the actual frequency which was being used for fixing. Eventually at a meeting held at Air Ministry on 2 March 1943, it was decided to use an extra frequency which would be available only from about 15 minutes before to 15 minutes after the critical period of an attack. The target frequency scheme was used from 8/9 April 1943, and although it did not work well at first, due to inexperience, things settled down, and by 26/27 April 1943 some fixes were obtained on all targets in the Ruhr area. The mean ranges obtained and the percentage of aircraft obtaining fixes were not nearly so high as in the pro-jamming period, but this may have been partly due to the fact that the use of the Pathfinder Force made intensive use of Gee in

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(1) 'Report on Operational Trials of Boozer.' Bomber Command O.R.S. Report No. S.86. (A.H.B./II/69/168).
(2) 'Gee Operational Ranges, February 1943.' Bomber Command O.R.S. Report No. S.85. (A.H.B./II H/241/2/547).
(3) 'Gee Operational Ranges, March 1943.' Bomber Command O.R.S. Report No. S.87. (A.H.B./II/69/210).
(4) 'Gee Operational Ranges, April and May 1943.' Bomber Command O.R.S. Report No. S.93. (A.H.B./II/69/210).

the target area less essential. ~~(Bomber Command O.R.S. Report No. S.93 refers).~~

Research into the accuracy of Gee

Phasing of the Ground Stations

At the beginning of 1942 and before Gee was used on operations, it was realised that the accuracy of a Gee fix was not only dependent on the ability of the navigator and the position of the aircraft relative to the ground stations, but also on a number of systematic errors which could be introduced at the ground stations. A visit was paid to Great Bromley monitoring station, and as a result it was possible to form an estimate of the nature and magnitude of the systematic errors which might arise due to:-

(a) errors due to incorrect manipulation

(b) fundamental limitations of the monitoring equipment

(c) discrepancy between calculated and observed co-ordinates of Great Bromley.

These errors were discussed in Bomber Command O.R.S. Report No. S.25.[1] It was found that from the first cause errors as great as 0.02 of a lattice co-ordinate could occur as the operators were unaware of the high accuracy required and were not making the best use of the equipment. It was recommended that operators should be provided with detailed instructions describing the most accurate way of using the equipment and that these should be rigorously enforced. The monitoring equipment had the same time base as was fitted to the aircraft receiver, and it was considered that since the ground personnel worked under very much better conditions than the navigators, an expanded and therefore more accurate monitor time base would be advantageous. It was found that there was a discrepancy between the calculated and observed co-ordinates of Great Bromley which was alleged to have constant values between 0.01 and 0.03 Gee units. This was most probably the result of incorrect phasing due to a number of causes, and it was recommended that the slave stations should be phased in such a way that the correct readings were given at Great Bromley. The recommendations made as a result of this investigation were carried out, and an improved monitor for Great Bromley was produced on high priority. A second

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(1) 'Accuracy of Gee - Phasing of Ground Stations.' Bomber Command O.R.S. Report No. S.25. (A.H.B./II/69/210).

investigation [1] ~~(Bomber Command O.R.S. Report No. S.27~~ ~~(27)~~ was carried out in conjunction with T.R.E. on the new equipment, and it was considered that the change permitted much greater accuracy in reading and therefore more careful monitoring. However, the modified equipment was not completely satisfactory and it was recommended that the possibility of eliminating the unsteadiness of the trace and improving its brightness should be investigated.

Following substantiated reports by navigators of Bomber Command, rendered in January and early February 1942, that Gee lattice co-ordinates were inaccurate to the extent of 0.1, 0.2 and even 1.0 units, a meeting was held at No. 60 Group under the chairmanship of the Air Officer Commanding No. 60 Group. Various possible causes were discussed, and it was decided to send representatives of Headquarters No. 60 Group and the O.R.S. to investigate the matter at the monitor station at Great Bromley. As recorded in Bomber Command O.R.S. Report No. S.32,[2] it was found that the monitoring operator was required to carry out a complicated procedure to watch the phasing of all three slave stations on the Eastern chain, and that this and careless operating could cause large errors. It was suggested that each slave station should be monitored independently and a simplified form of operating drill was devised. Small errors were already known to exist, and it was stated that work was being carried out both by T.R.E. and the O.R.S. to reduce these. Various other administrative points were investigated, and it was suggested that the chain should operate with a degree of monitoring accuracy dependent on the circumstances. Three grades were recommended:-

(a) Grade I giving the highest degree of accuracy for operations and training of aircrews.

(b) Grade II giving no guaranteed accuracy but providing training facilities for the operators, etc.

(c) Grade III main stations closed down with reserve stations switched on to provide for the maintenance of the main stations.

Whenever reserve stations were called upon to operate instead of the main stations, systematic errors were introduced into the Gee system since the transmitters could not be sited in exactly the same place. The O.R.S. carried out investigations into the magnitude of the errors introduced by the substitution of a reserve master station for the main station at Daventry on the

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(1) 'Accuracy of Gee - Phasing of Ground Stations II.' Bomber Command O.R.S. Report No. S.27. (A.H.B./II/69/210).

(2) 'Investigation into Accuracies and Reliability of Type 7000 Chain.' Bomber Command O.R.S. Report No. S.32.

Eastern chain ~~(Bomber Command O.R.S. Report No. S.34 (1) refers)~~, and a phasing procedure was devised whereby the lattice co-ordinates of the target were unchanged when the reserve station was in use.[1] It was also shown how corrections could be applied to ensure accurate fixing at any point on the route to the target. Another report ~~Bomber Command O.R.S. Report No. S.67 (2)~~ on the same subject was written when a new aerial was erected on the reserve site of the master station at Daventry.[2]

It was then discovered by the O.R.S. that certain discrepancies which had been known to exist between the slave and monitor readings were due to the fact that the slave station receiver aerials were not coincident with the transmitting aerials. The reading to be set on the cathode ray tube at the slave station differed from the nominal "phasing" value, and the readings at all slave stations for the Eastern and Southern chains for all possible combinations of main and reserve aerials were calculated.[3] ~~(Bomber Command O.R.S. Report No. S.68). (3)~~ The O.R.S. work on the phasing of ground stations was completed in May 1943. ~~by the publication of Bomber Command O.R.S. Report No. S.88 (4)~~ The report ~~which~~ dealt with the corrections to be applied to readings at the Master and Slave stations to give correct values at any given target for any combination of main and reserve stations.[4]

Errors in reading the Gee indicator

Apparent Alignment of Pulses

The homing technique which had been developed for use in operations was liable to two kinds of error, errors in setting up the required co-ordinates on the indicator and errors in judging when the pulses were aligned. An investigation into the second of these kinds of error, based on a series of trial flights carried out by No. 1418 Flight over Doncaster and Andover, using the Eastern Gee chain, was recorded in Bomber Command O.R.S. Report No. S.50.[5] It was concluded that the period of apparent alignment of the pulses was a function of the lattice spacing although there were insufficient results to determine the exact relationship, and that there was

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(1) ~~'Accuracy~~ of T.R. 1335 - Phasing of Ground Stations when using Reserve Master Station.' Bomber Command O.R.S. Report No. S.34.
(2) 'Accuracy of Gee - Examination of Errors involved by use of New Reserve Daventry Array.' Bomber Command O.R.S. Report No. S.67. (A.H.B./IIH/241/22/7).
(3) 'Phasing of Gee Ground Stations - Readings at Slave Stations'. Bomber Command O.R.S. Report No. S.68.
(4) 'Phasing of Gee Ground Stations when using Reserve Equipment at Master or Slave Stations.' Bomber Command O.R.S. Report No. S.88. (A.H.B./IIH/241/22/7).
(5) 'Accuracy of T.R. 1335 - Interim Report of Apparent Alignment of Pulses.' Bomber Command O.R.S. Report No. S.50. (A.H.B./IIH/258/3/12A).

a great deal of difference between the results of different navigators. It was also shown that by increasing the resolving power of the Gee indicator by using an expanded time base, it was possible to reduce the period of apparent alignment which, over the Ruhr, was estimated at between one and two minutes.

Observational Errors

Experience with Gee as a blind bombing device had shown that the accuracy obtained was not of a very high order, and that the bombs dropped had a scatter of several miles. The observational errors which could be made when using Gee due to errors in setting up the required co-ordinates when homing to a point and errors in reading the alignment of the pulses, were discussed in Bomber Command O.R.S. Report No. S.55.[1] To minimise these errors it was suggested that the ground stations should be phased in such a way that the second decimal place of the target co-ordinates would be zero. It was recommended that trials should be carried out to determine the increased accuracy to be obtained with this procedure. It was also suggested that the use of an expanded time base would facilitate determining the positions of the pulses, as was done at the ground stations. This new time base would also reduce the period of apparent alignment of the pulses. It was stated that operational navigators obtained results of much lower accuracy compared with the navigators of No. 1418 Flight, and it was anticipated that the suggested improvements would bring about an increase in the operational accuracy of Gee.

Effect of Pulse Shape

Reports were received from many crews that fixes taken over the Ruhr placed the aircraft well to the westward of their correct position. Further evidence of the existence of systematic errors was found in test flights carried out by No. 1418 Flight, and various operational squadrons over this

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(1) "Accuracy of T.R.1335 - Observational Errors." Bomber Command O.R.S. Report No. S.55. (A.H.B./IIH/241/10/89)

country. No. 60 Group pointed out that the pulses emitted by the Gee stations were by no means of constant shape and that the slope of the leading edge was subject to considerable variation. In Bomber Command O.R.S. Report No. S.58,(1) it was shown that the shape of the Gee pulses was very important and that much better results could be expected from triangular pulses, using the tips to estimate alignment. Measurements were made at a ground site on the effect of receiver gain on the indicator reading, and it was shown that a variation of about 0.02 Gee units could be obtained as the gain was varied from maximum to a value which made the pulse just visible. The error introduced was of such a sign and magnitude that it completely accounted for the reports made by operational crews over the Ruhr.

(1) 'Accuracy of Gee - Interim Report on Effect of Pulse Shape.' Bomber Command O.R.S. Report No. S.58. (A.H.B./IIH/241/10/89).

CHAPTER 12

INVESTIGATIONS INTO THE USE OF H2S AS AN AID TO BOMBING

The Principle of H2S

H2S was an airborne centimetric radar equipment which performed its main functions independently of any ground beacons. Developed from A.S.V. radar, its purpose was to present the operator with a map of the terrain over which the aircraft was flying in terms of characteristics such as coastlines, rivers, towns, hills and so on. These characteristics were distinguished by the relative strength of echoes returned from them by pulsed radio energy transmitted from the aircraft. The transmission was beamed in the vertical plane and scanned in the horizontal plane by means of a rotating reflector or scanner, so that in one complete rotation of the scanner (occupying one or two seconds) 670 or more pulses were emitted which 'illuminated' in turn successive sectors of the terrain below the aircraft. Echoes were received by the scanner during the periods between pulse transmission, and the source of these echoes could be identified and the positions determined from the relative strength of the echoes, the time delay of their arrival from the original pulse transmission, and the bearing of the scanner. To present this information logically to the operator, a 'plan position indicator' or P.P.I. was used in which a rotating radial time base swept in synchronism with the transmission from the scanner. The echoes were made to appear as a brightening of the trace on the cathode ray tube, so that as the scanner rotated a map was built up on the tube which corresponded in intensity to the characteristics of the terrain below. A variable range marker, which was incorporated into the picture and appeared as a bright ring, together with a transparent engraved bearing plate mounted in front of the cathode ray tube, allowed the operator to determine the range and bearing of the aircraft from any identified landmark, and a heading marker which appeared as a bright radial line in the picture enabled him to guide the aircraft towards a town and then carry out a blind bombing run. Briefly, these were the essentials of the H2S equipment, but numerous refinements were added in later versions to simplify its use or increase its accuracy. Mark IV, for example, broke away from the principles of range and bearing measurement used in earlier versions, although it still retained the P.P.I. type presentation described above.

Development of Operational Techniques

In the summer of 1942 the first aircraft to be fitted with H2S were allotted to No. 1418 Flight (which later became the Bombing Development Unit) for the initial service trials of the equipment. Air Staff requirements for H2S had specified that it should be possible to detect and home on to a built up area from a distance of 15 miles at 15,000 feet, and that the system should be accurate enough to ensure that when bombing with it, the bombs would fall in the area selected as the target. The directive for the trials was framed in the first place to discover the best bombing technique to be used and the accuracy that could be obtained with that technique, but although the value of H2S as an aid to navigation was not fully realised at that time the trials were also to investigate its possibilities in that direction. To assist in the execution and the analysis of the results, an O.R.S. representative was attached to No. 1418 Flight.

In the course of the service trials, several features of the equipment became clear. Owing to the difficulties of interpreting the P.P.I. picture it was not easy to use and required a training period of at least 20 hours - even then some operators failed to become proficient. It showed great promise, however, as a navigation aid, although its success as such was very much dependent on good dead reckoning work, again due to the limitations of the P.P.I. picture. Its use as a blind bombsight was disappointing. When the trials were completed, the O.R.S. representative was transferred to the Pathfinder Force to assist in the training of the first squadrons to be equipped, and the results of the trials were analysed by the O.R.S. at Headquarters Bomber Command. Bomber Command O.R.S. Reports Nos. S.83 (1) and S.84 (2) discussed the bombing results and made a comparison with those obtained by the squadrons during training. It was shown that the accuracy achieved was the same in both trials, and training, and that over a series of runs the average operator would be able to drop 50 per cent of his bombs within the mean radius of the main built up area of the town selected as the target.

(1) A.H.B./II/69/215A.

(2) A.H.B./II/69/215A.

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Furthermore, there was some evidence that this percentage would be constant and independent of the size (within reasonable limits) of the town attacked. The technique that had been adopted for bombing was known as the '30 second line method'. In this the aircraft was homed directly towards the target with the range marker ring set so that the release point should be reached 30 seconds after the target cut the ring, but the experience of H2S operators showed that in spite of the advantages of this technique, much of the difficulty of making an accurate bombing run was due to the fading and distortion of the target response, which took place on the P.P.I. at close range. A great deal of the T.R.E. development of the equipment was therefore devoted to improving the scanner and presentation which would preserve the definition in the centre of the P.P.I. So far as operational equipment was concerned, this work might be said to have culminated in the Mark IIIA - the main version of the three centimetre H2S which was in general use in Pathfinder Force by the summer of 1944. Both Pathfinder Force training results and the subsequent Bombing Development Unit trials of Mark IIIA showed that although considerable skill was still required to interpret the close range picture, it was possible under good conditions to follow the target response right in to the release point and so avoid the use of a 30 seconds timed run. The bombing results for the Mark IIIA quoted in Bombing Development Unit Report No. 30 Part 2,(1) showed that over a series of runs an operator would be able to drop 50 per cent of his bombs within two-thirds of the mean radius of the built up area.

H2S Mark IIIA, however, was never available in sufficient quantity before the end of the war, for it to be fitted into the whole of the main force, and even the Pathfinder Force were not able to make the best use of it until a year after it was first put into operational use. During this intervening period much effort was applied by the O.R.S. to the problem of increasing the accuracy and widening the application of the equipment by improved bombing techniques rather than by technical developments. The basis of most of the techniques proposed was that while a response at close range was distorted, broken up or generally difficult to interpret, the same response was usually

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clear and well defined at about ten miles range, so that if bombing could be carried out with reference to some feature of this range there was every hope that it would at least be easier if not more accurate than with the direct method. Besides providing an alternative of the direct method for bombing towns, these techniques allowed H2S to be used for bombing targets in which the responses from the aiming point were indistinguishable from that of the surrounding area, i.e. in cases where the aiming point was in the centre of a very large town such as Berlin, or in open country, or, as in high level mining at some point in an area of water. From their nature these techniques became known as reference point methods.

As a sequel to their initial trials of H2S, the Bombing Development Unit experimented with the use of the Ground Position Indicator (G.P.I.) with H2S, and developed a system of bombing with the two which constituted the first reference point method to be tried in practice. The method then adopted was to home the aircraft by H2S to a given range and bearing from some suitable reference point, and with the graticule set up to the corresponding position on the chart, to start the G.P.I. when that position was reached. From then on the aircraft was guided to the release point by the G.P.I. alone. The results of the trials of this method were discussed in Bombing Development Unit Reports No. 7, Parts 13 and 17,[1] in which it was shown that it would be suitable for attacking large defended targets but that against a small town the accuracy achieved would be less than that obtained by direct bombing. The method had various limitations and weaknesses, and several modifications were subsequently proposed to get over these difficulties. The first of these (described in Bomber Command O.R.S. Memo No. M.22[2] - ~~The use of H2S~~ and A.P.I. for Blind Bombing') was designed for immediate use by the Pathfinder Force and used the Air Position Indicator (A.P.I.) in place of the G.P.I., since at that time no G.P.I.s were to be ready for several months. In principle, it was similar to the original method and suffered from all its weaknesses, but as far as is known it was never given a full practical trial, and its only justification disappeared when the G.P.I. became available to the Pathfinder Force.

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(2) 'The Use of H2S and A.P.I. for Blind Bombing.' Bomber Command O.R.S. ~~Memo. No. M.22.~~

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A second modification, proposed and used operationally with considerable success by the Pathfinder Force, used the G.P.I. as in the original method but aimed at greater accuracy on the principle that the aircraft's position could be determined more accurately for synchronising the G.P.I. by taking a fix than by homing to a given range and bearing. With this method the graticule was set up on the reference point and the G.P.I. started at the moment that the H2S fix was taken (i.e. a measurement of the range and bearing of the aircraft from that reference point). The aircraft was then guided to the release point by the G.P.I., the aiming point on the G.P.I. chart having been displaced in the meantime from its true position by the range and reciprocal bearing of the fix.

Up till the end of the war only enough G.P.I.s had been manufactured to equip the Pathfinder Force, and so a third method was adopted by the squadrons engaged in high level minelaying. This required no G.P.I., and consisted simply in homing to a given range and bearing from the reference point, the range and bearing being calculated to give the position of the release point for the specified conditions of bombing. Without the G.P.I. it lacked the tactical freedom of the other methods, but this was not vital for mining and there was some compensation in the fact that it could be slightly more accurate than the original method by avoiding the errors of the G.P.I. There was, however, one other weakness of the method; the bearing plate could not be used simultaneously to show both the bearing from the reference point and the track of the aircraft. Many suggestions were put forward to overcome this difficulty, and a contribution to these was made in Bomber Command O.R.S. Report No. S.157.[1] One proposal made in this report was that the range and bearing should be set up on the P.P.I. by adjustment of the horizontal and vertical shift controls so that the reference point would finally lie under the centre of the bearing plate. This was very similar to the arrangements for reference point bombing made in the design of Mark IV H2S.

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(1) A.H.B./II/69/215(C).

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After the Command had gained some general experience in the use of reference point methods, it was decided that the Bombing Development Unit should carry out trials to compare the accuracy that could be achieved with these and direct methods for both Mark II and Mark IIIA (the two equipments then in operational use). The results of the trials which took place in the summer of 1944, were discussed in the Bombing Development Unit Report No. 56, Part 1.(1) In general, it was found that with each method of bombing, errors with Mark IIIA were about two-thirds those with Mark II, and that except when attacking a very small town, bombing with H2S and the G.P.I. was as accurate and sometimes more accurate than direct bombing, both methods giving appreciably better results than homing to a range and bearing.

The essence of all reference point methods was the determination of the range and bearing of a response, and a large proportion of the Bombing Development Unit trial was therefore devoted to an investigation of the fixing accuracy of H2S. During this investigation many abnormal errors were observed which were mainly associated with bearing rather than with range measurements, and since similar effects had been found by the Pathfinder Force in the course of a parallel investigation, the O.R.S. decided to make a special study of the problem. The results of the analysis of both the Bombing Development Unit and the Pathfinder Force flights together with evidence from ground tests and operational photographs of the P.P.I. were discussed in Bomber Command O.R.S. Report No. S.194.(2) In view of large bearing errors found, which were attributed mainly to the design and maintenance of the equipment, the report recommended that T.R.E. should consider incorporating a bearing marker which would be in future Marks similar to the heading marker and could be controlled by the operator, and that in the meantime maintenance personnel should give greater attention to accurate setting up of the equipment.

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(1) A.H.B./IVA/76/1.

(2) A.H.B./II/69/215(D)

/ Late

Late in 1944 a new bombing technique was proposed for H2S. This made use of Gee H, and since by that time both equipments were in common use and there was some urgency to have the scheme working operationally, the Service trials were carried out by No. 514 Squadron during their training. A description of the technique is given in Bomber Command O.R.S. Report No.S.204,(1) which served also as an instruction for training. The technique was designed to provide a means of bombing in those areas of the beacon coverage where the ordinary Gee H was impracticable either because the lattice angle of cut was very small or because the range was very great and only one beacon was likely to be received. To cater for this need it was proposed that the aircraft should carry out a normal Gee H run using the warning point method, tracking by means of the available beacon, but determining the moment of reaching the warning point by H2S instead of by a 'release' beacon. From the H2S point of view the technique was effectively another reference point method but with the major difficulty of tracking the aircraft accurately removed. To avoid the errors of bearing measurements, the H2S was to be used only to determine the moment when the aircraft was at a given range from the reference point, which for the greatest accuracy was chosen ahead or astern rather than on the beam of the aircraft. Bomber Command O.R.S. Report No. S.213(2) discussed the results achieved with the technique using H2S Mark IIIA and Gee H Mark I, and showed that in practice bombing 50 per cent of the bombs dropped within about one quarter mile of the aiming point. This accuracy was not far short of that achieved by Gee H alone.

To conclude this account of the Service trials, one other bombing technique might be mentioned, although it was only tried out over this country just before the end of the war. During the Service trials of H2S Mark VI which were carried out by two squadrons of the Command, it was found that very good grouping was obtained on each detail in practice bombing, but that large systematic errors along track were occurring which were believed to be due to errors of the range marker calibration. To get over this difficulty the O.R.S proposed a 'Mouse' system of bombing, in which the time taken for a response to

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(1) A.H.B./II/69/215(D).

(2) A.H.B./IIH/241/22/14.

/ travel

travel the diameter of the range marker ring was used to compute the delay required between the moment the target cut the ring and the release of bombs. The results of bombing runs carried out with this method showed that the systematic errors had been successfully eliminated.

Training

Following the success of the training scheme for Gee in operational squadrons, which was issued in June 1942, similar instructions were prepared with the introduction into the Service of both H2S and Gee H. Each of these instructions described a series of exercises which were to be carried out, giving details of the methods to be used in their planning and execution, with particular attention to the methods of assessing and recording the results, and to any special observations required for analysis purposes. The object of this was twofold; by specifying all the relevant conditions of the exercises in this way the squadron instructor was able more readily to assess the individual in relation to other pupils on a basis of the results he achieved, and secondly the O.R.S. was able to collect a large mass of homogeneous data in the form most convenient for analysis.

Bomber Command O.R.S. Report No. S.101,[1] giving instructions for H2S training, was drawn up on these lines with the assistance of the Bombing Development Unit Training Flight, which had been responsible for the training of squadron instructors since the end of 1942. When a large sample of results had been returned to the O.R.S. they were analysed and Bomber Command O.R.S. Report No. S.130[2] was written discussing the conclusions drawn from the work. Also analysed in this report were some of the results obtained by squadron instructors under training at Bombing Development Unit. It was found that although earlier Bombing Development Unit training results had fallen rather short of the accuracy obtained on trials, the introduction of the waveguide scanner in Mark II had improved the results for the period under consideration (winter 1943/44) and that the accuracy in both Bombing Development Unit training and Main Force training was such that about 50 per cent of the bombs could be expected to fall within the mean radius of the

(1) A.H.B./II/69/215(A).

(2) A.H.B./II/69/215(B).

/ main

main built up area - in other words the same standard that had been achieved in trials and Pathfinder Force training with the original equipment (see Bomber Command O.R.S. Report Nos. S.83[1] and S.84[2]). Two other facts were confirmed from these reports. Apart from variations caused by particular towns there was general relation between the 50 per cent error of bombing and the size of the town attacked - in fact they were approximately equal for a wide range of targets. Secondly, there was evidence that the drift of the aircraft was being ignored in making a bombing run, and it was therefore recommended that a track marker should be incorporated into the P.P.I. in addition to the heading marker as soon as production permitted, and that as an interim measure squadron instructors should place greater emphasis on making correct allowance for drift.

Other instructions prepared for H2S training can be summarised as follows: A revised version of Bomber Command O.R.S. Report S.101 was issued in the summer of 1944 as Bomber Command O.R.S. Report No. S.166.[3] This incorporated such modifications as were necessary in view of new methods originating with Headquarters No. 5 Group, and issued by that Group, dealing with exercises to be carried out with Mark IIIA using various bombing techniques. Another scheme was prepared in conjunction with No. 4 Group, for high level mining exercises. This was issued as Bomber Command O.R.S. Report No. B.228,[4] but unfortunately it was not carried through owing to the unavoidable limitation on training hours in force at that time. The instructions for training in the H2S/Gee H technique and the analysis of the results obtained in Bomber Command O.R.S. Report Nos. S.204 and S.213 have already been mentioned in connection with service trials.

The O.R.S. was particularly interested in another aspect of H2S training - the training of blind marker crews of the Pathfinder Force. Owing to the specialised duties of these crews the Pathfinder Force adopted exacting tests during 1944 by which they could be graded for ability. One test was to carry out a series of simulation bombing runs on a variety of towns in the U.K. Partly for the information of the Pathfinder Force and partly for record purposes, the O.R.S. analysed a sample of the results obtained on these bombing runs,

(1) A.H.B./II/69/215(A).
(2) A.H.B./II/69/215(A).
(3) A.H.B./II/69/215(C).
(4) A.H.B./IIH/241/22/12.

and found that for crews graded best using Mark III, 50 per cent of bombs would have fallen within half the mean radius of the main built up area. Thus the accuracy obtained was just twice as good as the Pathfinder Force's original training results, and although part of the improvement was to be attributed to the equipment, crew selection was clearly effective. A discussion of this analysis was given in Bomber Command O.R.S. Memo No. M.24.(1) In the summer of 1944 No. 5 Group, which at that time was also employing Pathfinder methods operationally, decided to adopt similar selection methods for their crews. A scheme was accordingly prepared by the O.R.S. in conjunction with Headquarters No. 5 Group on the basis of the experience of the Pathfinder Force. For reference, the details of this scheme have been published as Bomber Command O.R.S. Memo No. M.20.(2) Broadly speaking it involved analysis of both the training and operational results of a crew in navigation and bombing - an analysis which was to be carried out within the group.

Operations

The work done by the O.R.S. on the tactical use of H2S on bombing operations is described in Chapter 3. This chapter is concerned only with the study of the operational accuracy of the equipment as such. Naturally these two aspects have been closely related, and in describing the background in which the work had been done it is necessary to refer occasionally to the tactical side of the problem.

In January 1943 - a month before H2S was first used operationally - the O.R.S. prepared a note which outlined the various ways in which H2S might be used in bombing operations. Taking into account the accuracy of bombing achieved in trials and training and the effectiveness of past operations, it was concluded that the original policy of fitting H2S to all aircraft in the main force would lead to a considerably greater effectiveness of bombing than would be achieved by confining the equipment to the Pathfinder Force. However, the production of the equipment was so limited that for a time there were only sufficient sets to equip some 25 aircraft in the Pathfinder Force - clearly it was better to fit these aircraft first than not use the equipment

(1) 'Note on P.F.F. H2S Blindmarking Accuracy Tests.'
(2) 'Brief prepared for H.Q. No. 5 Group Assessment of Crews for H2S Blindmarker Duties.'

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at all until all aircraft could be fitted, and there is no doubt that whatever its shortcomings the use of H2S by the Pathfinder Force in those early days enabled attacks to be attempted which otherwise would not have been considered possible. It was not until October 1943 that more than 50 aircraft of the Main Force were equipped. The O.R.S. then proposed that as many of these trained crews as possible should be allowed to blind bomb on selected attacks, and that their results (as assessed from night photographs) should be compared with those obtained on the same attacks by aircraft not fitted with H2S. The object of this experiment was to determine whether the policy then adopted to reserving the use of H2S to blind marking by the Pathfinder Force was entirely justified, or whether the argument for its use by the Main Force put forward at the beginning of the year was in fact sound. The proposals were agreed and the experiment tried, but it was found that the results were not conclusive. This was mainly because very few of the aircraft returned plottable photographs, and of those that did do so it was by no means certain from their reports that bombing had been carried out by H2S alone and that they had not been influenced by the Pathfinder Force marking.

In April 1944 the matter was again raised. It was by then generally agreed that the limitations of Mark II H2S were such that the Pathfinder Force were unable to achieve an appreciably greater bombing accuracy with that equipment than the Main Force. In view of the success of an all H2S attack carried out by the Pathfinder Force against Ludwigshafen in November of the previous year (see Bomber Command O.R.S. Report No. S.112)[1] it was decided to arrange a similar experiment for Main Force blind bombing at the earliest opportunity. After discussion with the Air Staff at Headquarters, the O.R.S. prepared a plan for the experiment, but owing to the tactical commitments of the Command it was not possible to carry it out until August when it was laid on for the night 12/13th with Brunswick as the target. A discussion of this attack was given in Bomber Command O.R.S. Memo No. M.23.[2] In general, the experiment was a failure - a failure as an experiment rather than a failure

(1) A.H.B./II/69/215B.

(2) 'Night Raid on Brunswick, 12/13 August 1944.'

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~~as an experiment rather than a failure~~ as an idea - mainly through lack of experience of the crews, the majority of whom had been engaged exclusively on short range daylight attacks during the previous months and had therefore had little opportunity to practice with the equipment. Although it was agreed that the experiment should be repeated, no further opportunity arose before the end of the war.

During the first two years of its life then, H2S was only extensively used as a blind bombing or marking device by the Pathfinder Force. The accuracy of this marking was a subject for study by the O.R.S. for the whole of that time, and four main reports were written - at about six months intervals. The first of these (Bomber Command O.R.S. Report No.S.111)[1] covered the period from the first H2S operations in February 1943 to September 1943. It showed that the accuracy achieved was similar to that obtained in training in that over a series of attacks about 50 per cent of the markers were estimated to have fallen within the mean radius of the main built-up area of the target. The targets attacked, however, were somewhat larger than those used in training, so that the actual errors were greater. It also showed that as in training, operators were not making allowance for drift, thus confirming the need for a track marker on the P.P.I. One other important conclusion was that it was clear from the results and reports from operators that the targets attacked varied considerably as regards their suitability for H2S blind marking in that the quality of the response received was very much dependent on such things as the concentration of the built up area and the topographical features surrounding the town. The apparent importance of this factor in the success of blind marking led the O.R.S. to take a particular interest in the nature of responses. The work on this subject is discussed below under 'Target Intelligence'.

The second report in the series (Bomber Command O.R.S. Report No. S.189)[2] covered the period October 1943 to April 1944, during which time Mark III H2S had been introduced into the Pathfinder Force. It was found that over this period the accuracy obtained with Mark II was similar to that of the previous

(1) A.H.B./IIH/258/3/36.

(2) A.H.B./II/69/215(C).

/ period

period when measured in terms of error alone, but that owing to the smaller size of the targets attacked it represented a fall in the percentage of markers on the built up area (34 per cent instead of about 50 per cent). No satisfactory explanation for this effect was found except perhaps the adverse conditions of winter operations. So far as Mark III was concerned, the accuracy was the same as for Mark II except for attacks on Berlin where there was some slight evidence that Mark III had achieved more than Mark II, possibly due to the use of reference point methods on that very difficult target. In general, the performance of Mark III was disappointing and contrary to expectations, although this was no doubt due partly to inadequate training and lack of experience among maintenance personnel. This fact was confirmed in the subsequent period from May 1944 to September 1944 (Bomber Command O.R.S. Report No. S.200)(1) when it was found that Mark III had settled down to a very much improved standard of accuracy, while Mark II had returned to its original standard.

H2S Minelaying

So far this chapter has only been concerned with the operational use of H2S as a blind bombing and marking device, but one other application of the equipment should be mentioned - namely high level minelaying. High level minelaying first became possible with the introduction of the parachute mine, and the possibilities of using H2S to make it a blind technique were soon realised. A reference point method of bombing was developed for H2S in which the position at which the mine had to be released under the specified conditions of height, heading etc., was calculated before take-off and given to the operator as a range and bearing from a convenient reference point. Subject to the slight modification adopted from time to time by the individual Groups engaged on these mining sorties, this technique remained substantially the same from the time of its introduction. To assess the accuracy that had been achieved with this method of minelaying, use had to be made of the evidence of photographs taken of the P.P.I. with mine release, since no direct measurement of the position of the mine or aircraft could be obtained. Bomber Command O.R.S. Report No. S.179(2) discussed the analysis of a sample

(1) A.H.B./IIH/241/22/14.

(2) A.H.B./IIH/241/10/91.

of these photographs and showed that subject to the errors inherent in the evidence, 50 per cent of the mines could have been expected to have fallen within one and a half miles of the aiming point - a standard comparable with that obtained on trials of the reference point method of bombing with H2S (see B.D.U. Report No. 56, Part 1).[1]

Target Intelligence

In the early days of H2S, little was known about the relation between the pattern of responses on the P.P.I. and the features on the ground which caused them, apart from the fact that open country gave a stronger response than areas of water and a weaker response than towns, but it was soon clear that the successful application of H2S to both bombing and navigation was dependent on a more detailed knowledge of this relation. At first there was little that could be done in the way of a systematic investigation over enemy territory owing to security limitations, and the only data available was that obtained from operational reports. For example, reports showed that whereas mountainous country like the Alps gave recognisable hill shadows which could be of help to navigation, the same shadowing effect from the hills around Stuttgart made the response from the town particularly difficult to identify on a bombing run. Other examples of this indirect approach to the problem were the deductions drawn in Bomber Command O.R.S. Report Nos. B.124[2] and B.129,[3] which were written after the unsuccessful attacks on Wilhelmshaven on 19/20 February 1943, and Hamburg on 3/4 March 1943, respectively. In the case of Wilhelmshaven it was found that a new and extensive housing area to the north had been mistaken for the town itself because the run in to the target was from the north and no maps marked the new built up area. On the Hamburg attack the failure of the H2S marking was also attributed to misidentification. Operators had been briefed to use the neck in the river as a guide to finding the target, but owing to the low state of the tide and distortion on the P.P.I. the river appeared to be narrower than was actually the case, and a town some 10 miles downstream was mistaken for Hamburg. This property of H2S of distorting water boundaries was later investigated in trials (see B.D.U. Report No. 56, Part 2).[4]

(1) A.H.B./IVA/76/1.
(2) A.H.B./IIH/241/22/12.
(3) A.H.B./IIH/241/22/12.
(4) A.H.B./IVA/76/1

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Since this information on response generally and of enemy responses in particular depended primarily on the slow accumulation of operators' reports, a quicker and more reliable method was required if the mistakes of Wilhelmshaven and Hamburg were to be avoided. One obvious solution which the O.R.S. strongly recommended was to lift the security ban, fit a few H2S aircraft with cameras photographing the P.P.I. and detail them for reconnaissance flights over enemy territory. The shortage of H2S aircraft at the time prevented it from being adopted in Bomber Command, but towards the end of 1943 the security ban was lifted and a number of Pathfinder Force aircraft were fitted with miniature cameras with the object of taking photographs on operational sorties. The U.S. Eighth Air Force also carried out this scheme with great success when they were faced with the same problem with their H2X equipment.

At this stage P.P.I. photography began to assume importance in another role. This was to provide a plot of the position of the aircraft at any time, independent of weather conditions. If synchronized with bomb release, a P.P.I. photograph was clearly a valuable supplement to the night photograph as an immediate assessment of the success of a raid, and it was therefore decided to fit cameras to as many H2S aircraft as possible throughout the Command. For the guidance of the personnel who were to be responsible for plotting them, the O.R.S. prepared a note (Bomber Command O.R.S. Report No. S.121) [1] outlining the basic principles of H2S in their relation to P.P.I. photographs. An account of some of the difficulties to be encountered and the errors involved in plotting is given in Bomber Command O.R.S. Report No. S.179.[2] This report was actually written in connection with H2S minelaying, but so far as the P.P.I. photography was concerned the problems of plotting were much the same as in bombing operations. It showed that the position of the aircraft could not be determined very accurately in this way, and that since there was no automatic synchronisation with bomb or mine release the plot was much less reliable than the ordinary night photograph. The O.R.S. recommended that automatic synchronisation should be made a requirement for P.P.I. cameras, but owing to difficulties of production this feature was not available before the end of the war.

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(1) A.H.B./II/69/215(B).

(2) A.H.B./IIH/241/10/91.

As a result of this extensive fitting of P.P.I. cameras throughout the Command, many useful photographs were obtained, so that towards the end of the war records of the responses received had been collected for a large number of German towns. One group of photographs was a series taken over Berlin during the winter attacks of 1943/44, and to assist in planning and briefing for subsequent operations on this target these were assembled, together with maps and notes on their interpretation and issued by the O.R.S. as a 'target intelligence folder'. The O.R.S. later produced a similar folder of photographs made over this country, for the information of operators under training. The value of such folders having been demonstrated, the work was handed over to the Air Staff at Headquarters to continue.

This type of operational photography, however, was not a satisfactory basis for a general investigation into the relation between the responses received and the features causing them since H2S operators were not concerned as much with photography as with the job of making a successful bombing run. Because of this natural pre-occupation, the standard of photography was seldom high and the conditions such as gain setting, position of the aircraft and so on, could not be controlled to suit the investigator. For this reason it was decided to initiate trials over this country to obtain the required information, and since Berlin was then the principal target of the Command, London was chosen as the most suitable area for investigation. The flying and photography was carried out by the Bombing Development Unit, and the results were examined by the O.R.S. Bomber Command O.R.S. Report No. S.106 [1] described the experiment and discussed the conclusions drawn from the results. Reference should be made to this report for particular details, but no striking discoveries were made and the results mainly confirmed the observation of experienced operators, so that the chief value of the experiment was in reducing what was already known to a few into a systematic form and making the information available to all operators.

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(1) A.H.B./IIH/258/3/36.

Summary

During the early days of H2S there was much discussion on the scale of introduction into Bomber Command. It was held by some that it was so difficult to use that it should be restricted to the more skilled crews of the Pathfinder Force. The O.R.S. while agreeing with the difficulty of interpretation, envisaged that as later marks became available the equipment would prove easier to operate and therefore held the view that every aircraft should be equipped so that ultimately each could bomb the target independently. The O.R.S. felt that pathfinding, involving the use of flares and markers, could be no more than an interim technique, as it was so dependent on reasonably good weather conditions.

The policy adopted was of course for every aircraft to be fitted, but the equipment did not reach the hoped for stage of development whereby blind bombing could be universally adopted. The O.R.S. made every effort to determine by analysis of results obtained by odd crews during normal attacks, whether blind bombing by main force crews would prove to be accurate as pathfinder-led attacks and pressed many times for a few experimental attacks to be laid on to provide firm data on this question. Although as has been stated one or two attacks were made, the conditions mitigated against reliable results being obtained. While, therefore, it is unfortunate that the question was not settled satisfactorily, as there were many who considered that H2S should have been used for blind bombing, such evidence as the O.R.S. was able to amass tended to confirm that no increase in effectiveness would have been obtained by this procedure with the marks of H2S then available. In fact, the reverse would have been the case. The ultimate aim that every aircraft should be its own 'pathfinder' however, remained.

Although the success of raids carried out with its aid to pathfinding did not reach the consistent high standard achieved by Oboe, H2S was of great value to the Pathfinder Force. It was also of great value to the main force as a navigational aid, particularly in regions beyond the coverage of Gee (see Chapter 8 on Navigation). Therefore, although H2S failed to meet the original operational requirement, it played a vital role in Bomber Command's operations.

CHAPTER 13

THE USE OF GEE-H

The Principle of Gee-H

The principle used in Gee H was as follows. The aircraft carried a transmitter which radiated pulses. These pulses were received by a pair of ground stations sited on friendly territory. On reception of a pulse, the ground stations were 'triggered' and sent out an 'echo' pulse on a different frequency. The echo pulses from the ground stations were picked up by receiver equipment in the aircraft and were fed on to a cathode ray display locked to the transmitter pulses. By means of calibration pips, the time delays between the transmissions of the triggering pulse and the reception of the echo pulses from the two ground stations were measured in the aircraft. The position of the aircraft could thus be fixed by simple triangulation.

Development of Operational Technique

Two systems were considered for development as beacon radar navigational aids for the R.A.F. and in particular for Bomber Command during the summer of 1940. These were known as the Gee system and the H system. The Gee system was based on the measurement in the aircraft of phase difference between synchronised pulse transmission from three ground beacons. The basis of the H system was a direct measurement of the delay between transmission from the aircraft and echo transmissions from two ground beacons. Considerable discussion arose as to which of the two systems would be most suitable for development, and the main points discussed in various T.R.E. memoranda.(1)

Owing largely to the simplicity of the airborne equipment, the Gee system was selected for development as the chief navigational aid, and work on the H system ceased for the time being. In July of 1942 a requirement arose for a mass blind bombing device to supplement the Oboe marking system then planned and the H system on account of its accuracy was selected for development. Instructions from the Air Ministry to the Director of Communications Development for detailed examination of the H System were issued in a letter on 7 June 1942 and T.R.E. accordingly began work.(2)

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(1) T.R.E./L/M11/WBL (13 July 1942), T.R.E./HRJ/MB.D1919 (14 July 1942).
(2) Air Min. File CS/5154/Tels.1A.

The frequency band selected for the H system was the same as that of Gee so that the component units already in production could be used with little modification. On account of security reasons and in order that large scale raids could be carried out by staggering the periods of attack, a short time of transmission with the H system was essential; thus the H system could not be used for navigation as well. It was necessary that the change over to the H system from the navigation system should be very easy for the navigator. For these reasons and other technical reasons (e.g. the crystal control of the calibration pips had to be accurate to two or three places in ten), (1) it was decided to build the airborne H equipment round the already existing airborne Gee equipment; this was in the main by the addition of a transmitter, a modulator, and a 'black-out' unit. In a similar way it was found convenient to build the H ground beacons round the Gee beacons. The system thus became known as Gee-H.

The main feature of this system in so far as they impinged on operational requirements may be summarised as follows:-

(a) Up to 100 aircraft could use the system simultaneously; but not more owing to limitations of the power of the ground station.

(b) The range was expected to be of the order of 300 to 400 miles at 20,000 feet with station sites on the East coast, Ruhr targets could then be covered.

(c) Continuous monitoring of the ground stations was necessary to ensure that the beacon delays were constant; this monitoring unlike that of the Gee system could be carried out at the ground stations themselves.

(d) For security reasons and in order that there should be no confusion with identification of echo pulses the pulse recurrence frequency was 'jittered'; the (P.R.F.) was fixed at about 100 cycles per second, the minimum pulse recurrence frequency to ensure a continuous picture on the airborne cathode ray tube.

Pulse Recurrence Frequency

By March 1943 the design of the equipment was complete and production of Gee-H Mark I (A.R.I.5025) had been started. The standard document on the practical use of the equipment was the 'Gee-H Navigators' Manual' first published by Air Staff, Headquarters Bomber Command.(2)

At this stage the O.R.S. work on the equipment began, and discussions took place on the operational use of the equipment and the necessary

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(1) T.R.E./L/M13/WBL/1979 (23 July1942).

(2) Air Min. S.D.0544.

Service trials. During the period March 1943 to August 1944, the work centred round planning, discussions on the type of aircraft to be equipped, the accuracy to be expected, the use of Gee-H as a stand-by for Oboe Mark I, training programmes and techniques of bombing and homing. It was possible as a result of the trials by the Bombing Development Unit (B.D.U.) and T.R.E. and from experience obtained on Gee to give answers to most of these problems, although the B.D.U. service trials were not completed by the operational target date. The whole programme went through without a serious hitch, and the Command was ready to begin operations by the time the target date, 5 October 1943, had been reached.

Gee-H had been installed in four squadrons of Lancaster IIs, a technique for bombing and homing had been worked out, and the crews had been trained. In addition equipment of one Mosquito squadron of No. 8 Group had also ~~been~~ begun. The first operation took place on 8 October 1943 which was carried out by a Mosquito aircraft on Duren. The attack was regarded as a calibration attack to ensure that there were no large systematic errors (such as occurred when Gee was first used for blind bombing). The first main force operations by the four Lancaster squadrons took place on 3 November on Dusseldorf. This attack was highly successful as far as accuracy was concerned although the percentage of failures was rather high. Of the bombs dropped all appeared to be within a mile of the aiming point, which compared very well with an average of 10 per cent within a mile achieved on the best Oboe ground marking attack at that time.(1)

Unfortunately, however, strategic considerations prevented the development of this method of attack as far as operations were concerned; at that time, Berlin was the most important target and called for continuous maximum effort on the part of Bomber Command. Owing to the extreme range of this target it was impossible to use Gee-H for it, and as it was apparently not possible to reserve four Lancaster squadrons for special Gee-H attacks these squadrons did not use Gee-H again and it was removed from them in February 1944. However, during the period October 1943 to January 1944 the Mosquito attacks by Gee-H continued. These were on a very small scale, however, as No. 8 Group had never equipped more than two Mosquitos with Gee-H.

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(1) B.C./S.26419/1 (22 Nov. 1943).

The attacks they carried out were simply nuisance raids.

Up to December 1943 Gee-H was only used in Bomber Command; but from then onwards other Commands took interest in it, and eventually used the equipment for operations. As far as Bomber Command is concerned the history of the use of Gee-H was as follows. At the end of December 1943 there was some alarm concerning methods for countering the impending attacks by the German V.1 and V.2 weapons. As a result of this it was proposed that two Stirling squadrons should be equipped with Gee-H in order that the bombing of the flying bomb and rocket sites could be carried on in bad conditions of visibility. Stirlings were selected for this task as their use on Berlin operations had been discontinued owing to heavy losses.

However, by February 1944 it was felt that Gee-H bombing would not be a satisfactory countermeasure and it was decided to remove Gee-H from the Stirling squadrons. At the same time it was also decided to remove Gee-H from the Lancaster Squadrons and the Mosquito squadrons. Urgent representations were made by the O.R.S. and others that this would result in Bomber Command losing a valuable blind bombing aid, and in March it was decided that No. 218 Squadron (Stirlings) should be re-equipped to provide stand-by facilities for Oboe in the event of failure (due to enemy countermeasures) at a critical moment in the bombing offensive leading up to D-day (the landings in Normandy).

Actually the squadron was never used for marking although an operation was laid on on one occasion, and the operations by No. 218 Squadron, which were confined to half a dozen attacks on French and Belgian targets, were largely experimental. These attacks ceased at the beginning of May in order that the squadron could carry out trials and training for Operation Glimmer (part of the ~~occupation~~ deception plan for D-day). During the period from D-Day to the end of July, No. 218 Squadron carried out mining operations using Gee-H. At the end of July and during August Gee-H was used on attacks on flying bomb sites; the Gee-H aircraft of No. 218 Squadron leading formations of other Stirlings.

During all this period from the end of December 1943, continuous representations were being made by various organisations and individuals to

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get more Bomber Command aircraft equipped with Gee-H. In the middle of August 1944 the decision to equip the whole of No. 3 Group with Gee-H was finally taken. Large scale installations of equipment took place and by October 1944 a sufficient number of aircraft were equipped with Gee-H to enable No. 3 Group to carry out ~~large scale~~ extensive bombing operations using formations of aircraft led by Gee-H aircraft. From then onwards till the end of the campaign in North-West Europe No. 3 Group was operating continuously using Gee-H. The chief type of attack was the formation daylight attack, which was usually carried out by a gaggle of vics of three aircraft. Some night marking attacks were also carried out and on these attacks, for which high precision was essential, Gee-H aircraft alone were used. The device produced bombing which was of the same order of accuracy as visual bombing or visual bombing on Oboe markings, and had the great advantage that it enabled a heavy attack to be carried out in visibility conditions which precluded these two forms of attack. As the only alternatives to Gee-H attack were Oboe sky marking or H2S blind bombing (both of which gave relatively inaccurate bombing) No. 3 Group was frequently called on to provide front line support when weather conditions prevented the use of Oboe marking (e.g. during the Ardennes counter-offensive in December 1944 and the attack on Bremen on 20 April 1945).

Throughout all the time in which Gee-H was used in Bomber Command very few developments in equipment or technique were introduced. The Mark I airborne equipment was quite satisfactory and was used throughout with only very small technical modifications which were made as a result of the early T.R.E. accuracy trials. The ground stations used were Type 100 fixed stations or heavy mobile stations (same equipment in both types of stations). The light transportables were also used on occasions, but were found very unsatisfactory. The warning point technique was used throughout either with formations or single aircraft or marking attacks; but towards the end of the campaign the 'Mouse' technique was used on a few sorties by No. 218 Squadron.

All other developments such as Gee-H Mark II did not get beyond the trial stage. This was probably partly because of an absence of any German

/countermeasures.

countermeasures. During the whole period of the use of Gee-H no reports of jamming were authenticated; but it is known that the Germans were aware of the existence of the equipment by December 1943 (several aircraft had been lost over enemy territory by then), and later it wasknown that they were aware of the system which was known to them as 'Discus'.

As far as other users of Gee-H were concerned, the Eighth U.S. Air Force started using Gee-H in May in Liberators, and they used it until the end of the war. The chief interest in their operations was the use of the tachometric Norden bombsight as a 'Mouse'. This technique was found to be superior to the warning point technique which they had used at first. The Allied Expeditionary Air Force (A.E.A.F.) used Gee-H Mitchells of No. 2 Group from May 1944 onwards until the technique was replaced by S.C.R.584 bombing. The 'Mouse' technique was used on a number of their operations. Gee-H was also introduced into No. 38 Group after the Arnhem operation and an interesting technique was evolved for supply dropping by Gee-H. With all users of Gee-H a close liaison was maintained.

Mention should be made of the H2S Gee-H technique developed in No. 514 Squadron to deal with attacks on targets at extreme Gee-H range, or in areas only covered by one Gee-H beacon. The work on this technique is discussed in Chapter 12.

Study of Performance

Van trials of Fixed Group Stations

The first trials on the performance of Gee-H were those carried out by T.R.E. in 1943. The technical trials (e.g. technical performance of equipment at high altitudes) were carried out with little reference to the O.R.S; but trials on range and accuracy by T.R.E. were proposed and the details of these were discussed at a meeting at O.R.S. Bomber Command on 18 March 1943 (1) between the various parties concerned. The meeting discussed the various tests that would have to be conducted in order to obtain full information for theplanning of operational use. The trials proposed were :-

/(a)

(1) B.C./S.26419/1 (20 March 1943).

(a) Ground trials using on airborne set mounted in a test van to determine the limiting accuracy imposed by the apparatus.

(b) Low altitude flying trials over a camera obscura to determine the ability to home along a lattice line.

(c) High altitude homing and bombing trials; bombing with a stop watch 'Mouse' was to be tried.

A representative of O.R.S. Bomber Command was detached to T.R.E. for about three months just after the meeting referred to above and assisted in the trials. Of the proposed trials, however, nearly all the flying trials were carried out by the B.D.U. later in the year and are dealt with below. Exhaustive ground trials with a test van were carried out and at all of these the O.R.S. representative constituted a member of the team carrying out the trials.

The van tests were carried out using the two fixed ground stations in this country (at High Street, Halesworth, Suffolk, and at Grangewood, Hastings). The test was placed on various sites (chief among which was the Eastern Gee Chain Monitor Station at Barkway) and readings of the values of of the co-ordinate were taken on the airborne gear in the van. Discrepancies were observed between the actual readings and the theoretical readings, which were traced eventually to two causes:-

(a) A misunderstanding between T.R.E. and the Air Warfare Analysis Section on the method of allowing for ground station delay.

(b) The dependence of ground station delay in input signal strength.

The detailed results of the trials were not published, chiefly because no further discrepancies were observed in this particular series of van tests when these two factors had been allowed for. But the effect of signal strength on the various delays in the airborne and ground equipment is discussed in an O.R.S. note [1] and a method of overcoming the effects during operations was worked out and published by T.R.E. [2] In addition these trials showed that the strobe time-base presentation was liable to serious jitter; modifications were made to the equipment which successfully corrected this failing.

/The

(1) B.C./S.26419/2 (15 July 1943)
(2) T.R.E./D.2083/EF. (15 Oct. 1943)

The van trials continued intermittently during the period July to October 1943, and were completed by a series of continuous readings for seven consecutive days carried out by the newly trained W.A.A.F. Type 100 operators with O.R.S. supervision, and a further series lasting 48 hours carried out by representatives of No. 84 Wing. These confirmed the previous results (that all discrepancies were due to abnormally weak or strong signals) and van trials on the fixed ground stations were considered completed.

Van Trials of Light Transportable Equipment

By December 1943 the two prototype models of the light transportable beacons were produced by T.R.E. These beacons were primarily an A.E.A.F. requirement, but as no work had yet been carried out by A.E.A.F. the first trials on these beacons were carried out by Bomber Command and T.R.E. A meeting was held at O.R.S. Bomber Command to discuss these trials.(1) As a result extensive van trials and a range test were carried out by T.R.E. in conjunction with the O.R.S. The two beacons were set up at Grangewood and Worth Matravers and were known as the Gee-H Southern Chain. Later for operational purposes heavy mobile equipment was also set up at these sites.

Four series of van trials were carried out. In the first series, results were obtained on Grangewood which were considered reasonably satisfactory, errors of less than 100 yards being observed; but the errors observed on Worth at the two sites tried were both more than 400 yards. The second series of tests were therefore carried out on Worth alone. The results of these two series of trials were summarised in a letter circulated to all concerned (2) and the results were written up in an unpublished report and a copy was sent to T.R.E. (3) The anomalous readings observed on Worth at the two sites still remained, and much correspondence arose on the cause of the discrepancies. The third series of tests was carried out with the heavy mobiles sited along-side the light transportable beacons and the results of these tests were summarised in a T.R.E. report.(4) Again

/anomalous

(1) B.C./S.26419/2 (11 Jan.1944).
(2) B.C./S.26419/2 (18 Mar. 1944).
(3) B.C./S.26419/2 (18 Mar. 1944)
(4) T.R.E.D.2693/FBW (24 Apr.1944)

anomalous readings on Worth were observed at both sites, it was not until the fourth series of tests were carried out that progress was made in the matter. The results of this fourth series were published by T.R.E. (1)

The following conclusions were reached as a result of the completed series of tests:-

(a) There were no large systematic errors at Worth or Grangewood in either the heavy mobile or light transportable equipment.

(b) The two large errors observed at Worth were due, in the one case, to a computation error, and in the other case, to a reading error in the van.

(c) That the heavy mobiles ~~are~~ were more accurate than the light transportables on account of the greater accuracy of presentation and the ability of the heavy mobiles to measure complete beacon delay.

The B.D.U. carried out a small number of flying trials which confirmed that there were no systematic errors. The O.R.S. representative with this unit analysed the results which were published by the B.D.U. (2)

The range test was carried out by T.R.E. using a Mosquito, the results were given in a letter to the Director of Communications Development from T.R.E.,(3) and they showed that in respect of range the light transportables were also inferior to the fixed and the heavy mobile stations.

<u>Service Trials of Gee-H Mark I</u>

It was mentioned in the last section that the flying trials required to obtain data on the performance of ~~Gee~~-H were carried out by the B.D.U. rather than by T.R.E. These trials were discussed further at two meetings.(4) At these it was decided that the B.D.U. should carry out trials on Gee-H installed in a Lancaster Mark II. Homing runs and bombing trials were to be carried out; the accuracy of homing was to be checked with photographs of the ground and the accuracy of bombing was to be checked by quadrant readings from a bombing range. The B.D.U. were to obtain experience with the equipment before starting the trials; and these preliminary trials were to be runs over a camera obscura at Barkway, so as to serve as a check on the T.R.E. trials on that site.

The trials began in July 1943 with these runs over Barkway. O.R.S. representatives assisted in these trials and analysed the results for

/systematic

(1) T.R.E./D.2070/FBW (20 June 1944)
(2) B.D.U./S.521/Radar (5 Aprl.1944.)
(3) T.R.E./D.2347/RJD (26 Jan.1944)
~~(4) B.D.U./S.200/15/Sigs. (13 Jul.1943)~~
(4) B.C./S.26419/2 (11 June 1943) and B.D.U./M.S.200/15/Sigs (9 July 1943)

systematic error. The results which were unpublished agreed with the T.R.E. figures. Report B.D.U. No.19 Part 1[1] gave an account of the general serviceability of Gee-H on these trials. The homing trials were carried out at Llandow in South Wales; this area was chosen since the Gee-H facilities provided by the ground station approximated to those obtained over the Ruhr (where the chief Gee-H targets were expected to be). The O.R.S. assisted in these trials and analysed the results. These were published by B.D.U.[2] and established the following figures:-

(a) Probable (50 per cent) error about track = 100 yards.

(b) Probable (50 per cent) error about the release co-ordinate = 66 yards.

(c) Probable (50 per cent) error of heading = $2\frac{1}{2}^{\circ}$.

In addition to these figures there was evidence of systematic error, but as in previous T.R.E. trials it was finally decided that these could be attributed to signal strength errors at the ground stations.

Other conclusions drawn were as follows:-

(a) The number of aircraft using the system simultaneously had no detectable effect on accuracy.

(b) There was a tendency for systematic tracking errors to vary abnormally from flight to flight; this was attributed tentatively to wind determination errors.

(c) Bombing accuracy would be of the order of 400 yards so that bombing trials could safely be proceeded with.

It was chiefly on the basis of these trials that the first operational programme was planned.

The bombing trials were again carried out in South Wales, the bombing range being Stormy Down sea range. Three techniques of bombing were put forward for trial, all of which were based on the homing principle of homing down one lattice line. The techniques were designed to allow for the ground speed of the aircraft. They were :-

/(a)

(1) B.D.U/S.200/15/Sigs. (13 July 1943)
(2) B.D.U/S.200/15/Sigs. (15 Aug. 1943)

(a) Release point method in which the aircraft homed to a release point calculated on the basis of the met. wind before take-off at a predetermined height and air speed.

(b) Constant ground speed method; in which the release point was calculated as before, but on the basis of the wind found by the navigator, the bombing air speed was adjusted so that the ground speed of the aircraft was equal to that for which the release point co-ordinates were calculated.

(c) Warning point method; in which the aircraft did a short timed run from a warning point, the length of which (in time) depended upon the height and estimated ground speed of the aircraft and was obtained from a 'Warning period table', carried in the aircraft.

These three methods of bombing were tried out during the trials at Stormy Down. An O.R.S. representative flew on all the flights, noting times, speeds, headings, estimated errors and other data required for analysis. The computations were also carried out by the O.R.S. The ground station delays were specially altered in order that the co-ordinates of the release points should have zero second and third decimal places and one or two other refinements were also used.

The results of the trials were dealt with in two reports, one issued by B.D.U.[1] and the other issued by the A.W.A.S.[2] The chief conclusions drawn by these reports were :-

(a) The most accurate of the three methods was the warning point method; the average error using it was 335 yards as against 750 yards for the release point technique, and 490 yards for the constant ground speed technique.

(b) The warning point method was also the most practicable and gave the aircraft more freedom of height and air speed than the other methods.

(c) The incorporation of an automatic timing mechanism in the bombing circuit was recommended.

In addition the results showed that the systematic error of the system tended to vary from flight to flight, an effect which was found later to give considerable amount of trouble in operational bombing. No explanation for this variation was put forward as a result of the B.D.U. trials.

The main Service trials of Gee-H Mark I were then considered complete. But a further series of trials were carried out in June 1944 by B.D.U. on the Mark I airborne equipment as a result of the results achieved on operations by various users. The operational results are discussed in detail later; but the purpose of the trials was two-fold.

/(a)

(1) B.D.U/S.521/Radar (18 Nov. 1943)
(2) A.W.A.S/G/26 (21 Dec. 1943).
~~(3) T.R.E/D.2995/RAS (22 May 1944)~~

(a) To compare the results achieved by Bomber Command, Eighth U.S. Air Force and No. 2 Group (Second Tactical Air Force).

(b) To obtain data for investigation in systematic errors which had been noticeable on operations.

The trials were straightforward bomb dropping at Stormy Down range using the warning period technique. They were discussed at two meetings, one at (1) Church House and the other at O.R.S. Bomber Command.(2) The B.D.U. carried out their share of the trials with full O.R.S. co-operation.

The results were written up in a draft B.D.U. report.(3) As a whole the trials were a failure. This was for three reasons:-

(a) Neither the Eighth Air Force, nor No. 2 Group carried out their share of the work.

(b) The various scientific and service staffs concerned were largely devoting all their energies to Operation Overlord (the Allied landing in France, June 1944).

(c) The results obtained by the B.D.U. disagreed with both the van trials and the operational results which will be discussed later, but at the same time were far too scanty to draw any conclusions as to the cause of the disagreement.

It was felt by O.R.S. that the problem of systematic errors required a far larger mass of data than could be supplied by service trials, and the whole matter was dropped until this data became available from training flights, and operational data obtained in the winter 1944/45.

'Mouse' Trials

A 'Mouse' was a computing mechanism which carried out what were three distinct operations in the warning point method of bombing. It released the bombs at a point which automatically allowed for the groundspeed of the aircraft as measured directly on the run up by some external system, in this case Gee-H. The use of a 'Mouse' had advantages of accuracy and simplicity over other methods of allowing for ground speed. T.R.E. had originally proposed the use of a reversible stop-watch as a crude form of 'Mouse'; a suggestion which fell through partly because simultaneous manipulation of the stop-watch and the Gee-H equipment was complicated, and partly because great difficulty was experienced in obtaining any suitable stopwatches.

/In

(1) T.R.E/D.2995/RAS (22 May 1944).
(2) B.C./S.26419/2 (21 May 1944)
(3) B.D.U. Rept. 'Gee-H Bombing Trials at Stormy Down.'

In December 1943 it was suggested by the O.R.S. that a 'Mouse' could be constructed by carrying out relatively simple modifications to the already existing timing mechanism used in the aircraft for timing the warning period. Further it was suggested that the use of a 'Mouse' by aircrew would be greatly simplified if the Gee-H ground stations could be made to give out a double echo pulse, the two echoes corresponding to the two 'Mouse' reference points. Unofficial action was taken on these two suggestions to confirm that they were feasible. The B.D.U. carried out a small number of trials, using photographs to check the accuracy while T.R.E. modified a ground station to give a double echo pulse. The B.D.U. trials were carried out with the normal O.R.S. co-operation. The results achieved were not published in detail, but a figure of ± 33 yards for a probable error across the release co-ordinate was obtained, and quoted in an O.R.S. publication.[1]

This figure was regarded as being so good that its achievement was somewhat fortuitous.

These trials however showed that the scheme was feasible, and in June 1944, B.D.U. were instructed to carry out full accuracy trials of this particular 'Mouse' system (known as the Double Type 35 camera control 'Mouse' or the computer Type 59). These accuracy trials were of two kinds:-

(a) Analytical trials in which photographs of the ground were obtained at both reference points and at the target.

(b) Bomb-dropping trials.

The analytical trials were combined with accuracy checks on the new Gee-H beacon sited at Kilter (Cornwall). A proper model of the Type 59 Computer was not used for these trials, but a lash-up mechanism constructed at B.D.U. Further, the double pulsing scheme had been dropped, and the aircraft was homed to the two reference points by restrobing the release co-ordinate. The trials were carried out with full O.R.S. co-operation. The results, which were published in two B.D.U. Reports [2] showed that:-

(a) The hurried restrobing between the reference points did not appear to affect the accuracy of homing to the second reference point.

(b) There was a marked correlation between errors at the first and second warning points.

(c) With the accuracy of homing achieved by B.D.U., the 'Mouse' allowed for ground speed with errors of about ± five miles per hour.

/The

(1) Bomber Command O.R.S. Report No. S.156. (A.H.B./IIH/241/22/14).
(2) B.D.U. /S.521/1/Radar (8 July1944 and 16 Aug. 1944)

The B.D.U. then proceeded with the bombing trials. For these a slightly altered technique was used. The Type 59 computer required theoretically that the distance between the first and second reference points should be equal to the distance from the second reference point to the target. But on the trials, both reference points were chosen to have zero second and third decimal release co-ordinate; the fact that the theoretical conditions were not realised was allowed for by making a small correction (estimated on the forecast wind) to the time of bombfall. The results of the trials, which were published by B.D.U.[1] were considered disappointing (50 per cent error of 310 yards), but the large errors were attributed partly to inexperience of the operators concerned, and to a poor presentation on the particular Gee-H set used. A number of technical suggestions were made.

Further trials were carried out using a proper production model of the computor Type 59. The results of these trials [2] were rather more satisfactory (50 per cent error;160 yards) than those of the previous trials. This was attributed to the greater experience of the operators concerned, the improvement in the 'Mouse' equipment and the fact that a better Gee-H set was used. Further it was concluded that the results were highly satisfactory and that the automatic measurement of ground speed by the 'Mouse' was largely responsible. In spite of this the results of the two B.D.U. trials did show that the 'Mouse' system was unlikely to give a radical improvement in random accuracy and this was supported by the theoretical discussions given in the original O.R.S. report on the Gee-H 'Mouse' system.[3]

Gee-H Mark II Airborne Equipment

Gee-H Mark II consisted of the universal indicator Mark II and improved 'H' units. The Universal Indicator Mark II provided facilities for Gee-H and Rebecca. Aircraft which required these systems could thus avoid duplication of equipment. Bomber Command were concerned only with the Gee and H facilities. These were not radically different from those provided on

/on

(1) A.H.B./II/69/211.
(2) B.D.U./S.521/Radar. (4 Dec.1944)
(3) Bomber Command O.R.S. Report No. S.156. (A.H.B./IIH/241/22/14).

It was hoped, however, that a force equipped with 'Mouse' would not incur systematic errors in the estimation of ground speeds, and hence, the systematic errors incurred in operations (see below) would be reduced as far as along track errors were concerned.

Further trials were also carried out on the prototype of an electrical mechanical 'Mouse' designed by T.R.E. (the computer Type 56) when it was made available to B.D.U. in December 1944. It was not, however, subjected to trials with Gee-H Mark I, but was treated as part of the Mark II airborne equipment, and the Service trials of Mark II dealt with below included investigation into the performance of this 'Mouse'. It was concluded from the trials, however, that the computer Type 56 was a more reliable computer than the Type 59 (as indeed was expected) but there was no evidence that this produced a detectable improvement in accuracy except in so far as the proportion of gross errors was concerned. This completed the B.D.U. trials of the Gee-H 'Mouse' system.

Gee-H Mark I. The presentation was more stable, additional calibration pips were provided, and the time bases were of a suitable length to avoid the rather complicated time base and black out controls required on Gee-H Mark I. Maintenance of the equipment was supposed to be simple. But the pulses were of the same shape and the accurate strobe time bases were no faster, and so the equipment did not give a higher degree of resolution. At best, therefore, only a small increase in accuracy was expected, which would be due to an increased ease of handling, and to the more stable presentation.

One feature of the Mark II equipment was of interest; the 'B' and 'C' strobe time bases could be superimposed (this was a legacy from a requirement that the equipment should also provide Loran facilities). This enabled accurate 'hyperbolic' homing to be carried out. Normal homing was carried out by keeping one beacon pulse aligned with the transmitter pulse. Hyperbolic homing (so called because it resulted in the aircraft tracking along a hyperbola) was carried out by flying the aircraft so that on the strobe time base presentation, one beacon pulse was always aligned with the other. A full description of the Hyperbolic Homing Technique was described in B.D.U. Report No. 65 Part 2.(1)

The service trials of Gee-H Mark II were discussed informally with the various parties concerned, and three kinds of trials were carried out:-

(a) General serviceability and manipulation flights. Comparative range tests with Gee-H Mark I.

(b) Bomb dropping accuracy trials using normal homing and the computer Type 56.

(c) Bomb dropping and photographic accuracy trials using hyperbolic homing and the computer Type 56.

The trials were carried out with full O.R.S. assistance, and the results published by B.D.U. in three reports.(2)

The chief conclusions drawn from the trials were:-

(a) Technical modifications were required to improve the serviceability of the equipment.

(b) Manipulation of the controls was easier than on Gee-H Mark I but further improvements could be obtained.

/(c)

(1) B.D.U/S.521/Radar.
(2) B.D.U. Rept. No.65, Pt.2; A.H.B./IIH/241/10/97 (B.D.U. Rept. No.53, Pt.3) B.D.U/S.521/Radar (B.D.U Rept. No.65, Pt.I)

(c) The accuracy of bombing showed no improvement on Gee-H Mark I and a 'Mouse'.

(d) Hyperbolic homing was not feasible for operational use and the accuracy achieved was not greater than that achieved by normal methods.

(e) The range of Gee-H Mark II was consistently better than that of Gee-H Mark I by about 20 to 30 miles.

No trials of the Gee facilities were carried on.

Training Flights

Training flights carried out by the squadrons provided a large mass of homogeneous data suitable for analysis. The O.R.S. issued a report (1) which described how the flights were to be carried out in order that the data would be of the greatest value. In addition an O.R.S. representative spent a considerable amount of time at the squadrons giving direct assistance on day-to-day problems which arose in connection with the training. The training flights were of two kinds:-

(a) Homing to a point, checking the accuracy with photographs of the ground.

(b) Practice bombing, checking the accuracy with quadrant sightings on the smoke puffs from the practice bombs.

The photographs, together with the details of each flight, were sent to the O.R.S. who plotted the photographs and analysed the success obtained by crews on the various flights. Similarly, the quadrant readings of the bombs were sent in together with details of the flights.

The results of the first training programme (autumn 1943) were not analysed in great detail and no report was issued. This was partly owing to pressure of other work and partly because it was felt that the flights were not altogether satisfactory because the Gee-H reception on the flights was poor. (On account of weak signals owing to extreme range). However, the average radial error of the photographs was found to be about 500 yards with an average heading error of three to four degrees. The bombing accuracy was of the order of 900 yards. These results were sent to the squadrons in a letter from O.R.S. (2)

/Training

(1) B.D.U./S.26419/3 (Bomber Cmd. O.R.S. Rept. No.S.103) and BC/S.28043/44.
(2) B.C./S.26419/3 (18 Oct.1943)

Training flights lapsed in these squadrons after the autumn of 1943, but with the equipment of No. 218 Squadron, training received a new impetus. A revised O.R.S. memorandum on Gee-H training flights (1) was made in the light of previous training and operational experience for the flights. An O.R.S. representative again spent a considerable amount of time with the squadron assisting in the initial stages of training. The results of these training flights were analysed in great detail and were published in Bomber Command O.R.S. Report No. S.174.(2) The chief conclusions of this report were:-

(a) The 50 per cent error of practice bombing was about 300 yards.

(b) The chief causes of bombing scatter were attributed to:-

(i) Errors of Heading

(ii) Errors of tracking

(iii) Errors in estimating when the release pulse was correctly aligned.

(iv) Errors in estimating ground speed.

(c) The scatter of the mean point of impact of the flights was not unduly large.

These training flights enabled a fairly clear picture of the detailed performance of Gee-H to be built up, and thus provided a sound basis for the analysis of operational results. The accuracy achieved was considered very encouraging, and showed a great improvement over the earlier training flights, which was thought to be partly due to the improved conditions under which training was carried out. Later in 1944, when the whole of No. 3 Group was equipped with Gee-H, the results of the training flights of Nos. 149 and 514 Squadrons were also analysed in detail. The results were not published, but the figures obtained for the various types of error agreed extraordinarily closely with those obtained by No. 218 Squadron, and the conclusions of Bomber Command O.R.S. Report No. S.174 were completely confirmed. Further analysis of Gee-H training flights was discontinued after this, as it was felt that the results achieved by No. 218 Squadron were sufficiently representative.

/'Mouse' Training

(1) Bomber Cmd. O.R.S. Rept. No. S.103. (A.H.B./II/69/211).
(2) A.H.B./II H/241/22/14.

'Mouse' Training

In the spring of 1945, No. 218 Squadron were equipped with the computer Type 59 (The Type 35 Camera Control 'Mouse'.) The work carried out by the O.R.S. was exactly parallel to that carried out for the normal training flights. An O.R.S. Report (1) gave details of how the flights were to be carried out. An O.R.S. representative was attached to the squadron and the flights were analysed in detail. The results which were published by the O.R.S. (2) led to the following chief conclusions:-

(a) The results showed considerable improvement over the warning point practice bombing, (330-430 yards).

(b) This improvement was not entirely due to the direct tactical use of the 'Mouse' but was also caused by improvements in the performance of the ground station.

(c) Computer Type 59 was an inferior Mouse mechanism in the respect of accuracy, serviceability, and ease of manipulation. It was recommended that the computer Type 59 should be superseded by the computer Type 56 as soon as possible.

This work on the 'Mouse' was completed after the end of the war. No training flights were carried out with the Type 56 'Mouse' or with Gee-H Mk.II until after the end of 1945.

Operations

The study of the performance of Gee-H on operations was started with the first operation - a calibration attack on Duren on 8/9 October 1943 by a Mosquito of No. 139 Squadron. This attack was planned in order that it should be confirmed that there was no gross systematic error (i.e. greater than a mile or so) in the Gee-H system before main force operations commenced. The Mosquito obtained a photograph which showed that the bombs fell about 600 yards beyond the target. In view of the results obtained on Service trials and on training and of the errors involved in night photography this error was considered to be quite consistent with the absence of a large systematic error in the Gee-H system. The A.W.A.S. issued a short report on the operation (3) which confirmed these results.

/The

(1) A.H.B./II/39/1/1 (Bomber Cmd. O.R.S. Rept. No. S.103).
(2) Bomber Cmd. O.R.S. Rept. No. S.248. (A.H.B./IIH/241/22/14).
(3) A.W.A.S. Note No.21 'Analysis of Gee-H attacks on Duren, 8/9 Oct.1943.

The first main force operation was the attack on 3/4 November 1943 on a factory on the outskirts of Dusseldorf. Maximum effort was devoted by the O.R.S. to ensuring that the fullest possible information should be available. T.R.E. and O.R.S. representatives were at each of the stations and interrogated all the returning crews. Strike photographs were obtained by eight aircraft, and P.R.U. cover was obtained. The results which were analysed and published by O.R.S. (1) indicated an average error of about 800 yards. Ground station performance, and propagation performance were also studied, and the high percentage of aircraft failing to receive one of the ground stations gave rise to some anxiety. Nevertheless, the results of the attack were considered very encouraging, and the accuracy achieved was considered to be a radical improvement on the accuracy achieved by main force aircraft bombing on Oboe ground markers. The results obtained by analysis of the strike photographs were confirmed later by the results of an expert examination of the P.R.U. cover by R.E.8 (Ministry of Home Security).

No further operations were carried out by the main force, until April 1944, and those carried out by the one Gee-H Mosquito of No. 139 Squadron provided no more accuracy data, but minor investigations of signal strength on these operations were undertaken in order to provide T.R.E. with data for research into propogation. A full scale operational range test by aircraft of No. 115 Squadron was carried out (raid on Frankfurt, 20/21 December 1943), from which it was apparent that 300 miles was about the limit of Gee-H range from the ground stations. (2)

The next operations were carried out by No. 218 Squadron in April 1944. Four bombing operations were carried out in April, and the results obtained

/from

(1) Bomber Cmd. O.R.S. Rept. No.S.110. (A.H.B./II/69/211).
(2) B.C./S.26419/1 (13 May 1944).

from them were published by the O.R.S. [1] The accuracy achieved on these attacks was of the order of a 50 per cent circle about the aiming point of 500 yards. But two alarming features were shown by these raids. In the first place the number of aircraft failing to receive the stations was high and appeared to be due to weakness on the air to ground link. Secondly, there was a marked tendency for the systematic error to vary from raid to raid, both along the track and across track.

As far as the failure of a large proportion of the aircraft to receive the ground stations at 200 miles at 15,000 feet was concerned, a series of flying trials and range tests were carried out by aircraft of No. 218 Squadron in conjunction with O.R.S. and T.R.E. Complementary work was carried out at the ground stations concerned. Great difficulties were experienced in detecting the weak aircraft transmitters owing to the absence of testing gear for measuring field strength. The conclusions of these trials were as follows:-

(a) A proportion of aircraft transmitters were appreciably weaker than others.

(b) By careful maintenance all aircraft could receive the ground stations (which were heavy mobiles and not fixed stations) at 220 miles at 15000 feet but the maximum safe range at this height was 200 miles.

(c) There was nothing wrong with the aircraft's aerial arrays, or with the ground stations.

The systematic errors were not explained. The ground station at Worth Matravers was under considerable suspicion of being responsible, because the ground trials which yielded anomalous results were then being carried out (see above). Meetings were held with other users and it was found that similar errors had also been encountered (by the Eighth U.S. Air Force) on the Eastern Chain. It became apparent that Gee-H operations suffered from variable systematic errors which could be so great as a mile, and no cause for this was obvious. It was finally concluded (faute de mieux) that the only way these errors might be eliminated was by the use of a 'Mouse'.

/Apart

(1) Bomber Command O.R.S. Report No. S.152. (A.H.B./IIH/241/22/14).

Apart from an attack on 1 May by No. 218 Squadron no further Gee-H bombing operations were carried out until July 1944. In the intervening period No. 218 Squadron were fully occupied with Operation Glimmer until D Day, and after that concentrated on mining the French ports using Gee-H. From these operations propagation data was obtained.

Gee-H led formation attacks began with an attack on the flying bomb installations at Vieulles de Neuve on 27 July. These attacks generally were carried out with a Gee-H leader and deputy leader, with a rough formation of anything up to twelve aircraft following. They were the first attacks carried out using Gee-H in daylight. Six attacks of this type were carried out; all during the period 26 July to 31 August. Three of them were analysed (using strike photographs) and the results published in Bomber Command O.R.S. Report No. S.183.[1] The chief features of these raids were a very high standard of accuracy on the part of the Gee-H leaders (average error 275 yards) and very poor backing up by the followers. Two other attacks were analysed; but the results were not published. The analyses, however, indicated that the accuracy achieved on the three previous raids was partly fortuitous and that the figure of 500 yards for the average error fitted the overall picture better. Loss of accuracy from systematic errors was again apparent; formation flying could be improved. These raids, however, provided very useful experience for the attacks which began in October, in which the whole of No. 3 Group flew in formations led by Gee-H aircraft.

During the period from October 1944 to the end of the war 94 Gee-H attacks were carried out; 76 of these were formation attacks, Gee-H aircraft leading Vics of three aircraft; ten were ground or skymarking raids, and eight were blind-bombing attacks by Gee-H aircraft alone. Assessments of the results of these attacks were based on three sources of evidence:- strike photographs, crater plots and target indicator plots. All the raids which yielded information from either of these sources were analysed. The

/first

(1) A.H.B./IIH/241/22/14.

first O.R.S. Report [1] gave an account of the accuracy achieved on two ground-marking attacks. The 50 per cent error on these attacks was 630 yards and the percentage of gross errors, 27 per cent.

The raids carried out during the period October to December 1944 were fully dealt with in a further O.R.S. Report [2] which was designed to show the general characteristics of Gee-H bombing. No attempt was made to go into details as to the exact causes of errors. The chief conclusions of the report were:-

(a) Gee-H bombing gave an average radial error of 1027 yards (all types of raids) with 20 per cent gross errors outside the 2,500 yards circle.

(b) The overall accuracy achieved by formation attacks was about the same as that achieved by the Gee-H leaders alone.

(c) The overall systematic error was negligible, but on individual operations the systematic error was liable to be relatively large (1000 yards or so).

These results were regarded in the light of previous results, and of training results, as being disappointing. This low accuracy achieved was felt to be largely due to inexperience both with formation flying and with handling the Gee-H equipment. Nevertheless, the results improved steadily throughout the spring of 1945. These were also analysed in detail. The research was particularly directed to find out the relative magnitude of the various errors (just as was done on the No. 218 Squadron training flights) and particularly to track down the cause of the systematic errors which had remained totally unexplained since they first appeared in No. 218 Squadron's early operations, of April 1944. The main conclusions of the work, which were published by O.R.S. [3] were:-

(a) The accuracy of Gee-H on these raids was an improvement on the raids analysed in the Bomber Command O.R.S. Report No. S.211. Two or three of the raids, in particular, were outstanding with 50 per cent errors of 500 yards.

(b) The detailed analysis showed that the errors of tracking were of the order of   yds. Errors of heading of the order of   , and that systematic wind finding errors of the order of 15 knots were incurred by the navigators.

Unfortunately comparison of the results obtained by crater plot with those obtained by photographic evidence showed serious discrepancies on the one or two raids on which both methods were used and this prevented further detailed work on the causes of the large systematic errors which were present /on

(1) Bomber Command O.R.S. Report No. S.199. (A.H.B./IIH/241/22/14).
(2) Bomber Command O.R.S. Report No. S.211. (A.H.B./IIH/241/22/14).
(3) Unpublished report by Bomber Cmd. O.R.S.

on these raids. It was concluded, therefore, that the study of performance of Gee-H at that time was still incomplete in this respect but no further work was carried out between the end of the war and the end of 1945

Advisory and Planning Work by the O.R.S.

General Policy

The section dealing with the general history of Gee-H covers a large portion of the work under this heading. On most of the points mentioned in the historical summary the O.R.S. were consulted. In addition, however, work of a consultative nature on such problems as frequency allocation and deployment of ground stations was continuous throughout the war; and it will be appreciated that such work was not confined to Air Staff at Bomber Command, but a considerable amount of it was done in conjunction with other users and organisations such as No. 60 Group, and Director of Radar at the Air Ministry. The great proportion of this work was either verbal or can be found on the minute sheets of various files concerned with Gee-H. However, by giving an account of the work involving O.R.S. publications, good examples of the work can be given.

When it became known that the equipment was to be available for Bomber Command, O.R.S. took part in preliminary discussions on the use of the device. The main points put forward by the O.R.S. may be found in two O.R.S publications.[1] The discussion centred round the following problems:-

(a) How does Gee-H compare with other radar blind bombing and navigation aids?

(b) Should Gee-H be used for navigation or bombing or both?

(c) Estimated performance and susceptibility to jamming.

(d) Suggestions as to which aircraft it should be installed in.

The suggestions outlined in this report were largely agreed to by Air Staff. The O.R.S. was involved very fully in detailed work on training flights and operational planning, and because of this, they were very much concerned with the operational target date; and in a memorandum [2] advised that it be put

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(1) Bomber Command O.R.S. Report No. S.82. (A.H.B./IIH/241/22/14).

(2) B.C./S.26419/1 (15 Jan.1943).

back from 1 October to 8 October. As a matter of interest this document gives a very clear idea of the sort of work the O.R.S. was concerned with at the time of Gee-H. In another memorandum (1) the types of target to be attacked were discussed. Later after the target date had been reached and no operations materialised, there was considerable pressure from the O.R.S. to get the device used. As has been described earlier in the chapter only nuisance raids were carried out after the main force raid on Dusseldorf and further suggestions on general policy laid considerable emphasis on the value of the service. After Gee-H had been removed from all aircraft in the Command in February 1944 it was suggested (2) that Gee-H should be used to back up Oboe marking in the attacks on railway targets; and this suggestion was agreed to and resulted in the re-equipment of No. 218 Squadron.

As far as the ground station side of this work is concerned reference may be found to various O.R.S. suggestions in the minutes of meetings held at Air Ministry in the summer of 1943. One of these suggestions should perhaps be mentioned, that the ground stations should have a regular pulse recurrence frequency superimposed on their irregular pulse recurrence frequency from noise and aircraft triggering, in order that it should appear to the enemy that the stations were merely search equipment on a new frequency band. This suggestion, however, was not taken up. Mention should also be made of the O.R.S. proposals put forward in the summer of 1944 for the combination of the eastern and southern G-H chains in Bomber Command O.R.S. Report No. S.136; (3) assent was given to these suggestions.

Techniques of Homing and Bombing

This section covers the work done by O.R.S. after the general policy and use of the equipment had been fixed, and is concerned with the investigation into the best methods of bombing by Gee-H. The problems of Gee-H bombing were in the main two-fold. Firstly, by means of Gee-H, the aircraft was homed to a point and investigations were necessary to determine the best technique for reducing errors of heading, tracking and releasing to a minimum. Secondly the position of the point at which the bombs were released to hit a given aiming point depended on a large number of factors, not all

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(1) B.C./S.26419/1 (6 Sept. 1943)
(2) B.C./S.26419/1 (24 Feb.1944)
(3) A.H.B./IIM/a1/4a App. O.R.S.

of which could be accurately estimated before take-off; methods of allowing for these factors in the air had to be worked out.

The first problem had been partly solved as a result of the use of Gee for homing. The principle used in Gee of flying along one lattice line and waiting until the other line was crossed was also the only practical one to use with the presentation of Gee-H Mark I. The chief aim of the methods suggested was to reduce heading errors, which, as stated above, appeared to be the largest single source of error and these methods were basically attempts to overcome the lack of rate-aiding of Gee-H. Three methods of tracking were described in the O.R.S. Report No. S.103; (1) two of these were fundamentally obvious methods and were used by B.D.U. in the Service trials, and gave no real opportunity for obtaining an accurate course from the Gee-H presentation.

The third method (the rate of changing course method) was worked out by the O.R.S. and was primarily designed to enable the navigator to treat the Gee-H lattice line (which was circular) as a straight line. An account of the method was also published separately by O.R.S.,(2) chiefly because the deduction of a simple relationship between a small change of course and a corresponding change of track was felt to be of general interest. The method was officially recommended by Air Staff but it was never really used by more than a small percentage of navigators, the majority ofwhom continued to use the ordinary empirical methods which involved turning on to precomputed headings at the warning point.

On account of this, at the end of 1944, the O.R.S. was asked to investigate the possibilities of other methods; so that when the Gee-H training flight was set-up, a standard method of tracking could be taught. This resulted in a method known as the 'Chord Method'.(3) The method was tried by aircraft of the Training Flight, and the results achieved were very good; but the method was thought to involve too much complex work for the navigator and was dropped in favour of the rate of change of course method. No further methods were put forward, and it was felt that short of improving the sensitivity of the presentation, the accuracy of tracking could only be improved by the introduction of a proper rate-aiding device.

/Another

(1) A.H.B./II/69/211.
(2) BC/S.26419/1 (14 Oct.1943)
(3) B.C./S.26419/1 (14 Oct.1943)

Another suggestion for improving the accuracy of homing to a point was put forward in order to avoid serious errors along track resulting from tracking errors when the angle of cut of the lattice lines was small. This was known in general as the 'I' and 'U' line method and was described in the Navigator's Manual.(1) The hyperbolic homing suggestion for use with Gee-H Mark II never got beyond the trials at B.D.U., as already described, but there was general agreement with the B.D.U. view that hyperbolic homing involved too much resetting of the Gee-H controls for general operational use.

To the second problem of Gee-H bombing, that of allowing for the various factors on which the position of the release point depended, the O.R.S. contributed a number of solutions. The difficulty was as follows:- complete allowance could easily be made for all factors before take-off and the co-ordinates of the corresponding release points given to the crews. But such a release point was then based on a met. wind and depended on the aircrew adhering to a pre-determined height and airspeed and this involved appreciable errors. Alternatively, by the time the navigator had found an accurate wind, and decided on the best conditions of height and airspeed for bombing it would be impossible to expect him to carry out the necessary computations to obtain the co-ordinates of the required release point. Moreover it was desirable that all aircraft should home to the same pre-determined point, so that by special phasing of the beacons the co-ordinates of the point could be given zero second and third decimal places. Ground speed was the factor which caused most trouble, since an accurate knowledge of it was essential for accurate bombing, whereas a pre-determined height and airspeed could be adhered to sufficiently accurately and anyhow allowance for these factors was not difficult.

Four methods were proposed, the first three of which were tried in the B.D.U. Service trials. The first of these was the met. wind method, the second was the constant ground speed method and the third was the warning point method. Descriptions of these methods can be found in B.D.U. Report No. 19, part 3. (2) which covered the results of the trials; and in

/addition

(1) Air Min. S.D.0544. (2) B.D.U/S.521/Radar (18 Nov.1943)

addition the warning point method is described fully in Section I of O.R.S. Report No. S.103.[(1)] This method was adopted for operational use and was practically the only method used in Bomber Command during the war and was also adopted by other users as a standard bombing technique.

The fourth method put forward was the 'Mouse' method. The principle of the 'Mouse' was of course well known and had been successfully applied to Oboe; but its use for Gee-H had been held up by lack of suitable mechanism. As has been stated the original T.R.E. proposal for the use of a stop-watch as a 'Mouse' was rejected; but tentative proposals for a 'Mouse' system involving the timing mechanism already in use with the warning period method, of bombing, and double pulsing at this ground station were put forward and subjected to unofficial B.D.U. trials in December 1943. The full O.R.S. proposals together with a theoretical discussion and the results of the B.D.U. trials were put forward by O.R.S. in Report No. S.156.[(2)] Much correspondence and discussion on these proposals arose between the various users of Gee-H, T.R.E., No. 60 Group and the M.A.P. and further proposals were put forward by T.R.E. in a demi-official memorandum.[(3)]

A full account of the various discussions is not possible, but they centred round four main proposals;-

(a) Production of the 'Double Type 35 Camera Control'. 'Mouse' suggested by O.R.S. (4)

(b) Design and production of a proper electrical/mechanical constant speed 'Mouse'.

(c) Design and production of a variable ratio 'Mouse'.

(d) Double pulsing at the ground stations.

It was eventually decided for technical reasons firstly to drop the double-pulsing scheme; secondly, to drop the variable ratio 'Mouse'; thirdly to produce on a crash programme 50 double T.35 Camera Control computers (the Computer Type 59) and, finally to design and produce in large numbers an electrical/mechanical 'Mouse' (which became the computer Type 56) to be produced by a commercial firm.

/Owing

(1) A.H.B./II/69/211.
(2) A.H.B./IIH/241/22/14.
(3) T.R.E./D.1979/135a/EF. (16 May 1944).
(4) Bomber Command O.R.S. Report No. S.156. (A.H.B./IIH/241/22/14).

Owing to production difficulties, neither the Type 56 nor the Type 59 was available in sufficient numbers before the end of the war to have any effect on the operational accuracy of Gee-H. The biggest disadvantage of the Gee-H Mouse system (using either of the computers) was the necessity for restrobing the release co-ordinate between the two reference points. But in spite of pressure from the various users, no further proposals were put forward to avoid this, after the rejection of the O.R.S. double pulsing scheme.

This covers the work by the O.R.S. on the technique of homing and bombing used in Bomber Command, but as part of the general liaison with other users the development of the American tachometric Norden bombsight. technique and the No. 38 Group methods for supply dropping were discussed at some length.

Details of Operational Use

The O.R.S. were always very closely concerned with the details of operational use and planning with Gee-H, more so probably than with any other device. This was partly because the O.R.S. were required to carry out calculations for the operations in support of the Normandy Landings ~~(dealt with in a section below)~~ and partly because the nature of the operation was largely experimental for a long time. The work fell into three main sections:-

(a) The planning of the operation at Headquarters.

(b) Calculations for the operation (dealt with below).

(c) The detailed work at the R.A.F. stations concerned.

The planning work at Headquarters Bomber Command was largely concerned with such problems [redacted] as the direction of approach, method of bombing and the use of mixed bomb loads. [redacted] This work which began with the first operation was continued until the large scale use of Gee-H was well under way in the autumn of 1944.

During the early stages of the use of Gee-H O.R.S. representatives were present at most of the stations partly to ensure that the necessary data for the study of performance was collected properly. But these representatives also gave a considerable amount of assistance to the navigation staff in the daily problems arising on the stations and in a number of cases, briefed the crews on the Gee-H conditions of the attacks. Similarly when the crews

/returned

returned from the operations, interrogations were carried out by O.R.S. personnel. Towards the end of 1944 when the large scale use of Gee-H made this detailed work impossible and very largely unnecessary, briefing forms and interrogation questionnaires were provided by O.R.S. and forwarded to No. 3 Group for use by the navigation staff and the stations; regular liaison visits were paid by the O.R.S. to the stations concerned.

Details of Training

It has already been mentioned that training flights provided valuable data for the study of performace of Gee-H. It was natural, therefore, that the Air Staff at Bomber Command should wish to ensure that the training flights were carried out so that they would supply as much data as possible; and following the practice which had been started with Gee, O.R.S. produced their requirements for training flights in the form of a report which was then passed on to the groups by Air Staff.

~~In the case of Gee-H the suggestions for the training flights and all the data for them were supplied by O.R.S. in O.R.S. Report No. S.103.~~ For the first Gee-H programme (autumn 1943) only a provisional report was issued,(1) together with an Air Staff document on practice bombing (2). ~~Both these reports were issued in this demi-official form because of shortage of time.~~ Eventually the two were combined and issued as O.R.S. Report No. S.103 and this document eventually became the standard work for instructors in Bomber Command and was complementary to the Navigator's Manual. In the spring of 1945 it was re-issued with several modifications as Headquarters Bomber Command Memorandum on Training Flights. Thus although the training flights were no longer required to supply data for analysis the original report provided a sound basis on which training flights could take place.

In addition to this work O.R.S. representatives at the stations naturally maintained a close liaison on training matters with the squadron instructions, and later, with the Gee-H training flight, after it was formed in the spring of 1945. The training flights for 'Mouse' were similarly a matter in which the O.R.S. played a considerable part. The O.R.S. Report No. S.203(3) ~~gave details of~~ provided a guide to the planning of the training flights and supplied a considerable

/amount

(1) A.H.B./II/69/211.
(2) B.C./S.26419/3 (26 Sept.1943)
(3) A.H.B./II H/241/22/14.

amount of information on the detail of using the device . An Addendum to this report was published [1] in order to supply new co-ordinates and details of a testing procedure. In addition to this work an O.R.S. representative was attached to the squadron for various periods to assist in the day to day problems which arose.

In the summer of 1944 T.R.E. suggested that various users might find a training film useful. Bomber Command were not in a position at that time to put up a requirement for a film. However, No. 2 Group put up a requirement which was supported in general terms by Bomber Command and the Eighth U.S. Air Force. Most of the basic work on the film was carried out by the T.R.E. Film Unit in co-operation with No. 2 Group. But O.R.S. were asked by the Air Staff at Headquarters Bomber Command to ensure that the film fitted Bomber Command usage and technique as far as possible. On this account the O.R.S. maintained a close liaison with T.R.E. and No. 2 Group, and suggested a number of modifications in the text and lay-out most of which were incorporated. These suggestions are to be found in the minutes of a meeting held at Headquarters No. 2 Group.[2]

Calculations

As stated above the calculations required for Gee-H operations were a matter in which the O.R.S. was partly responsible. The calculations for Gee-H operations were of two sorts, firstly the basic calculation of the ranges from the ground stations to the aiming point and, secondly, the corrections of these ranges in order to obtain the co-ordinates of the warning point. The A.W.A.S. were entirely responsible for the basic calculations. Until No. 3 Group computing section was set up in October 1944 the second part of the calculations were entirely the responsibility of the O.R.S. Calculations for operations using 'Mouse' were also the responsibility of the O.R.S.

The first method of calculation of the warning point co-ordinates was proposed by the A.W.A.S.[3] This method of calculation was discussed with the A.W.A.S. and it was concluded that unnecessary errors would be incurred

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(1) B.C./S.26419/3 (25 May 1945)
(2) B.C./S.26419/3 (1 Aug. 1944)
(3) A.W.A.S. W.R/E.M. (12 Aug. 1943) and W.R./J.M.E., 30 Sept.1943.

by its use and a second method was agreed to. After this method had been used once or twice in the early operations, various modifications were made to the formula in order that the calculations could be carried out conveniently by slide-rule, (the A.W.A.S. did all their calculations on computing machines). The proformae and the formulae used were gathered together in an O.R.S. File.[1] These slide-rule formulae were also used by the computing section at No. 3 Group. However, later in 1944, further discussions with the A.W.A.S. took place which led to a radical change in the formulae used. In a further A.W.A.S. publication,[2] exact mathematical formulae were put forward which, with very small modifications, could be made more accurate and just as simple as the original ones used by the O.R.S. This report also gave a summary of the previous formulae used.

In addition the new A.W.A.S. formulae were easily adaptable to 'Mouse' calculations. However, the formulae given in this A.W.A.S. note were never used, and the A.W.A.S. produced further modifications giving still simpler results just after the issue of the report. The 'Mouse' calculations were also based on this new formulae which was used by the computing section and were described in a letter from Bomber Command O.R.S. to the A.W.A.S.[3] The formulae used by the O.R.S. for the 'Mouse' calculations were given in an unpublished note;[4] the O.R.S. preferred to use these formulae as they were designed for use with the slide-rule.

In addition to these calculations, a good deal of work was carried out by the O.R.S. on subsidiary formulae, collecting ballistic data, aiming of mixed loads and the aiming of cluster projectiles. In a memorandum,[5] the methods of aiming mixed loads are described. In addition the O.R.S. supplied a considerable amount of direct assistance and information to the No. 3 Group computing section on all these matters.

Calculations of warning period tables (for use with the warning point technique) was largely a matter for the A.W.A.S. But the first warning period tables were calculated and produced by the O.R.S. together with a description

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(1) B.C./S.26419/4/O.R.S
(2) A.W.A.S./W.R./D.M.H./M.B.S. (21 Dec.1944)
(3) B.C./S.26419/4 (16 May 1945)
(4) B.C./S.26419/4 (20 Feb. 1945)
(5) B.C./S.26419/4 (15 Dec.1944)

of the assumptions made and the factors allowed for.[1] Subsequently when the various modifications were introduced into the warning period tables such as calculating them for constant R.A.S. instead of constant T.A.S. and methods of using one set of warning period tables for various bombs were worked out. In general, however, the O.R.S. laid down the specifications of the warning period tables to meet the requirements of the Command and the tables themselves were calculated and produced by the A.W.A.S.

Miscellaneous

This section deals with two pieces of work in which the O.R.S. were involved with Gee-H which were not part of the normal Gee-H programme. The first was work done in connection with Operation Glimmer and the second was work done in connection with the use of Gee-H by the Bomb Ballistic Unit.

Operation Glimmer was a naval-air feint against the beaches at Boulogne carried out at the same time as the main landing in Normandy on 6 June 1944. Aircraft of No.218 Squadron carried out advancing orbits dropping Window to give the effect of a large convoy. The details of the work carried out by the O.R.S. on the quantities of Window and other radio countermeasure devices involved is covered in Chapter 17. In addition, however, O.R.S. carried out work on the details of the navigation required and the training of the squadron. As Gee-H was used in conjunction with Gee to enable aircraft to carry out orbits accurately, this work is described below.

The work on the operation began about a month before D day and involved superimposing the lattice lines of the High Street Gee-H station on an Admiralty chart of the south-eastern Gee chain. The aircraft flew towards the French coast on one set of High Street lattice lines and at the appropriate moment, as determined by the value of the Gee co-ordinates, carried out a rate one turn which brought them facing towards the English coast on to another set of High Street lattice lines. The aircraft then homed towards the English coast and when they reached a point as determined by the Gee lattice lines, which were slightly in advance of the original starting point, carried out another rate one turn which brought them on to the original set of High Street lines facing towards the French coast. This type of orbit was repeated some 30 to 40 times, a small advance of about a quarter of a mile being made with each succeeding orbit so that the Window screen advanced at the same rate as the naval vessels below. /The

(1) B.C./S.26419/1 (27 Oct.1943)

The calculation of the co-ordinates of the various turning points and the preparation of the data for the crews were carried out by the O.R.S. In addition elaborate precautions were taken to ensure that in the event of a failure of either Gee-H or Gee, the aircraft would have some means of carrying on the orbits; and this involved calculations of further co-ordinates of the turning points using the Grangewood Gee-H station and another set of Gee lattice lines. An O.R.S. representative was attached to the squadron to assist in the trials and training flights. The trials, however, were not extensive as all the basic work had been carried out already by T.R.E. or No. 617 Squadron for the similar Operation Taxable (a feint towards Cap d'Antifer) which was carried out at the same time. It was discovered through the interrogation of high ranking prisoners of war after the end of hostilities that the operation was a complete success.

The use of Gee-H in the Bomb Ballistic Unit (B.B.U.) was proposed in the spring of 1944 when it was found that the ballistic data of many bombs, and in particular target indicators, was unreliable. Up till then the B.B.U. had relied entirely on visual methods for obtaining ballistic data on the bombs; this restricted the work to clear weather, and thus resulted in ballistic trials from high altitudes taking a long time. Accordingly it was suggested that radar bombing should be used and at a meeting at the M.A.P.(1) proposals were put forward for the use of Gee-H. Extensive preliminary discussions also took place between representatives of the O.R.S. and Research and Development Armament 14 in the M.A.P. The proposal to use Gee-H was accepted and aircraft of the B.B.U. were fitted in the summer of 1944. Apart from minor liaison work, the O.R.S. carried out no further work in this connection.

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(1) M.A.P./S.B.56015 (R.D. ARM.3) - Feb.1944.

CHAPTER 14

THE OPERATIONAL USE OF OBOE

The Oboe Principle

During the years 1940 and 1941, No. 109 Squadron was detailed to carry out special duties. One of these special duties was the examination and destruction by bombing of the beam bombing system used by the enemy. The method used was to fly back along the beam to its source. In order to determine the exact moment of release, experiments were carried out at T.R.E. using a C.H.L. station together with a Peacock (a modified I.F.F. set) to measure the range of the bomber and to send a release signal to it. These initial experiments led to the formation of the Oboe scheme of blind bombing on which work was then started.

The Oboe scheme consisted of two ground stations, one the 'Cat' or tracking station and the other the 'Mouse' or releasing station. These stations, working on different Pulse Recurrence Frequencies (P.R.Fs), triggered a transmitter-receiver (the Peacock) in the aircraft which sent back another pulse to the ground station. The ground stations then measured the range of the 'peacock' response using the usual radar technique with large cathode ray tubes and a fast time base. The pulses sent out by the two ground stations were modulated in different ways, and when these signals were received by the aircraft Peacock they were fed into a filter. This filter separated the two signals and fed the modulation as a tone to the pilot and bomb-aimer in the aircraft, the pilot hearing only the modulation sent out by the tracking station and the navigator receiving that sent out by the release or mouse station. The tracking station sent out dots or dashes. Dots were transmitted when the aircraft was nearer the ground station than the target and dashes when it was further than the target. Near the target range an automatic device (the Double Strobe) was used so that as the range was increased the dots were faded through an equisignal note into dashes. The pilot of an Oboe aircraft, therefore, heard a signal like a very narrow Lorenz beam, the centre of the beam lying on a circle at constant

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range (the range of the target) from the tracking station. The Oboe pilot attempted to fly as accurately as possible along this beam, and so fly on a circle which eventually passed over the target. In addition, to dots or dashes, the tracking station also could send out morse letters, which were used as call signs for the aircraft and to provide warning signals ~~to indicate~~ indicating to the pilot ~~how far he was~~ his distance from the beam.

The navigator, on the other hand, received signals from the releasing station. As in the case of the pilot's signals, these in the first place consisted of the 'Mouse' call sign and of warning letters indicating how far the aircraft ~~was~~ was from the target. Finally, as the aircraft approached the target, a semi-automatic device known as a 'Mouse' was used. This 'Mouse', as already explained,[1] worked out the ground speed of the aircraft (assuming it was flying accurately 'on the beam' provided by the tracking station, and at the correct height and air speed) and sent a release signal at the appropriate moment, on receipt of which the navigator pressed the bomb switch.

Although the 'Mouse' took into account the ground speed of the aircraft, there were various corrections which had to be applied to the range setting of the target. These allowed for the trail of the bomb, the cross trail, the fact that the bomb was thrown along a tangent to the track and so on. Some of these corrections had to be based on the estimated Met wind, but except with the low terminal velocity bomb these corrections were only second order quantities.

It will therefore be seen that with the Oboe system it was hoped to provide an accurate blind bombing device using a system of ground control all the accurate measurement and calculation being done on the ground under the direction of a controller. The aircraft was to fly merely according to the ground station's direction, using the automatic narrow beam to keep the aircraft on track, and releasing on the directions of the ground station. The accuracy of measurement was thought to be about 20 yards. The system would of course be limited by the range of reception of the pulses from the ground station. Work was to be started (Mark I) on the C.H.L. wavelengths (120 - 130 mc/s), but it was hoped ultimately to develop a ten centimetre system (Mark III and II). The chief limitation of the system was clearly that one pair of ground stations could only deal with one aircraft every ten to 15 minutes. It was hoped ultimately

(1) See p. 268.

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by the use of special filters and the ten centimetre system to provide multiple P.R.F. working so that one pair of ground stations could deal with several aircraft.

Research and development work was started in the summer of 1941 by T.R.E. on the Oboe system as described above. The flying was provided by a flight of No. 109 Squadron with Wellingtons.

Although Oboe was potentially a very accurate system of bombing it was of little interest to Bomber Command in view of its limited handling capacity and limited operational range. For example, it could only be used to attack the Ruhr from heights of at least 26,000 feet and therefore would not be used by the main bomber force even against the nearest targets in Germany. Its development was consequently proceeding only on a very low priority.

Studies by the O.R.S. of bombing operations had shown quite clearly that, provided the aiming point was clearly visible or a conflagration could be started, a very successful bombing attack could be carried out. The great difficulty was to find the aiming point in the first place. While pondering on this problem the O.R.S. conceived the idea that if Oboe aircraft could drop a distinctive mark on the aiming point at 'zero' hour and replenish it, say, every three minutes, an accurate and easily seen aiming point would be provided for the whole of the bomber force. This would require, say, four pairs of ground stations and one squadron of high flying aircraft such as Wellington VIs or Mosquitoes.

This suggestion was put to the Air Staff at Bomber Command as a method for attacking the important Ruhr targets, in Bomber Command O.R.S. Report No. S.53.[1] The Air Staff considered that the scheme was practicable and suggested that the latest marking bomber known as the Target Indicator or T.I. which was then being developed, was ideally suitable for the purpose. The Air Ministry were accordingly asked to arrange for the development of Oboe to proceed on the highest priority.

(1) A.H.B./ID/12/196

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The proposal to use Oboe for target marking was probably the greatest contribution to the increase in the effectiveness of bombing operations. All the extremely difficult targets in the Ruhr against which very little success had been achieved were very severely damaged during the first Oboe attacks and the method enabled the precision attacks against marshalling yards to be carried out with the minimum of effort and minimum damage to occupied territory. The various precision attacks in preparation for the re-entry into Europe and many attacks in support of army operations were dependent on this technique.

No. 109 Squadron was transferred to Bomber Command and later became part of the Pathfinder Force when it was formed in August 1942. Tests to determine the suitability of Wellington VI and Mosquito aircraft for the scheme were carried out, and although it seemed at one time that neither would be satisfactory, the personnel of No. 109 Squadron showed great persistence and succeeded in installing the equipment in a Mosquito. This proved to be satisfactory and this aircraft was selected. The Mosquito was able to carry four of the new target indicators which when dropped in salvo provided an excellent distinctive mark.

<u>Nature of Work on Oboe Conducted by the O.R.S.</u>

The general organisation of the technical development and research into the operations of Oboe was somewhat different from that in other spheres. With Oboe, the squadron which ultimately used the equipment on operations was the same squadron which carried out the development work. A lot of the initial difficulties were, therefore, eliminated. Moreover, the whole organisation of Oboe, although complex (concerning T.R.E., No. 60 Group, No. 109 Squadron, No. 8 Group, controllers, aircrew etc) was small, so that modifications in technique could be done on a 'personnel' level. Some of the special investigations conducted have been written up in the operation of Oboe, but much work was carried out by investigation on the spot, followed by verbal advice and discussion with the R.A.F. personnel concerned, and is not therefore recorded. The member of the O.R.S. attached to Headquarters Pathfinder Force assisted in the planning of Oboe operations and in much of the day-to-day analysis of results, but in view of the intensity of the operation little has been fully written up.

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It is therefore not intended to mention specifically in this chapter each job done by the O.R.S. - except insofar as where full reports have been written, or special investigations carried out - but a general history of the use and development of Oboe will be given. It is of interest to note that in view of the highly specialised nature of this operation, the O.R.S. frequently acted as the Command's executive representative at Air Ministry meetings on matters connected with development of the system.

First Operations (Mark I)

The equipping of No. 109 Squadron with Mosquitos, the selection of suitable crews, and their training, and the establishment of two pairs of ground stations on the East Coast (at Dover and at Trimmingham) to give cover over the Ruhr was proceeded with as rapidly as possible during the autumn of 1942. Towards the end of this period, however, just when the crews were nearly trained, the system received serious interference from some unknown source. This interference effectively spoilt a large proportion of the test and training flights. Furthermore, it completely prevented the tests on the accuracy and reliability, and on the navigation accuracy and timing achieved by the crews. It had been hoped to conduct these tests exhaustively before committing the device to marking operations over Germany. It was, however, finally decided to postpone the full trials in this country until the interference had been cleared up. Instead some operational trials were to be conducted on actual targets in Germany or occupied territory. The first attack was on 20 December 1942, by six Mosquitos (each carrying three 500 pound bombs) on a power station near Sittard in Holland. Three aircraft attacked successfully, but evidence of accuracy was not obtained, as when eventually a P.R.U. photograph was obtained it was found that the target had been attacked previously.

During the next few weeks several similar operational trials were carried out and also some attacks against Ruhr targets. In addition, a few experimental sky-marking attacks were carried out in which the Oboe aircraft dropped flares above cloud as a release point marker for

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~~(1) A.H.B./IIH/241/22/7.~~

a small number of main force aircraft. Some of these early experimental and training flights were analysed in considerable detail and are described in Bomber Command O.R.S. Report No. S.78.(1) This report showed that the reliability, the timing and the navigation were satisfactory. The little evidence obtainable regarding accuracy suggested an average error of ~~the~~ about 600-700 yards, together with some suggestion of a few gross errors of the order of a mile. Both of these errors were considerably in excess of what was expected, but were nevertheless sufficiently promising to justify further trials.

<u>The Battle of the Ruhr</u>

The special attacks were continued throughout February and a few attempts were made at ground marking operations with small numbers of aircraft in rather poor weather conditions. Firm evidence of the accuracy was still not available but the general technique was considered to be sufficiently reliable for an attack to be made on the night of 5/6 March 1943 on Essen by a force of about 400 aircraft. The technique was basically quite simple and similar to that originally envisaged by the O.R.S. Aircraft flying at 28,000 to 30,000 feet marked the Oboe with red target indicators (T.I.) approximately once every five minutes (there were two Oboe channels - two pairs of stations working on different frequencies - each channel being able to deal with one aircraft every ten minutes). To provide continuity (as the T.Is only burnt for a few minutes) and to guard against failure of Oboe aircraft, 'Backers-up' were provided. These Backers-up, which were normal heavy bombers, dropped Green T.I. visually on the Red T.I. (or on previous greens if no reds were visible). The main force bombed the Red T.I. if visible, otherwise they bombed the Green T.I. This technique as used on the first big Oboe ground marking operation proved an outstanding success. This most difficult of targets which had been attacked on numerous occasions in the past with very little effect, was very severely damaged - the greater part of the old town of Essen was completely burnt out and much damage done to Krupps Works.

(1) A.H.B./IIH/241/22/14.

/Throughout

Throughout the summer of 1943 this same technique was successfully used against the important towns within range in what became known as the Battle of the Ruhr. The ground marking technique used proved to be by far the most successful developed by Bomber Command up to that time, and damage was done on a scale never previously achieved by night bombing.

The results of these early Oboe attacks are given in Report No. S.102. (1) This report showed that these Oboe ground marking attacks had greatly increased the overall effectiveness of Bomber Command's operations. Although there was little evidence on the accuracy of Oboe itself, it was undoubtedly sufficient for the immediate task in hand. The accuracy, however, did not appear to be quite up to expectations; there appeared to be a systematic error of about a quarter of a mile together with a random error of about the same magnitude. The report strongly recommended an increase in the number of Oboe channels from two to four or even eight. This would provide greater continuity of marking and would effectively cover gaps due to unreliability. The provision of a system less vulnerable to jamming (as yet not experienced) and the development of a repeater system to give greater ranges were also considered to be urgent operational requirements.

During July 1943, a third Mark I Oboe channel was provided on the East Coast giving cover over the Ruhr. This was of considerable assistance and improved still further the results of attacks on the Ruhr area during the summer. In July 1943 the Battle of the Ruhr was over, and Bomber Command started to attack targets at greater range - beyond the Oboe coverage. Thus, although Oboe was used for occasional raids on targets within range, it was only used on a small scale during the ensuing months. Oboe had, however, fulfilled all our expectations but, as will be seen below, it still had tasks of the greatest importance to perform.

Winter 1943 - 1944

The winter 1943/44, sandwiched between the Battle of the Ruhr and the period of intensive work on Oboe for D-day, was a period of technical change and modification. Largely at the instigation of the O.R.S., two

(1) A.H.B./IIH/241/22/14.

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committees were formed. The Oboe Panel which met at the Air Ministry every few weeks was formed to thrash out the many problems connected with Oboe, particularly the complex problems arising from the technical capabilities and limitations of the system. At the meetings of this panel, representatives of T.R.E., No. 60 Group, the O.R.S., No. 8 (Pathfinder) Group and Headquarters Bomber Command, worked out many such problems and arrived at agreed recommendations. This arrangement was found necessary in view of the complexity of the organisational side of Oboe, where frequently in any given problem, one member would only see part of the picture. The other committee which met first in September 1943 at the A.W.A.S. was the Accuracy Committee. Various members were in receipt of evidence on the accuracy of Oboe, and the committee was formed to co-ordinate their data and to co-ordinate future action. This committee later lapsed, as with the intensive work conducted on the accuracy for D-day the work became centralised at Headquarters No. 8 (Pathfinder) Group.

Jamming of Mark I

During the autumn of 1943 a fall off in Oboe performance was observable, and after considerable difficulty in tracing the exact cause, part of this loss in performance was attributed to enemy jamming of the system. After considerable test and experimentation a system known as K-Oboe with latching was introduced. This involved each Mark I ground station radiating pulses on two wavelengths, the pulses being sent out a few microseconds apart. The aircraft receiver was only actuated if both pulses were received and at the correct spacing. The aircraft then transmitted back on a third frequency. This system was found to reduce considerably the effect of the enemy interference. It was, however, found that with the frequencies in use with K-Oboe, the three channels were subject to mutual interference when used in the presence of interference. In view, therefore, of the increasing availability of the Mark II channels, it was eventually decided to use only two Mark I channels (Channels 1 and 3) for operations, while the remaining channel (Channel 2) was to be used for training only.

/Mark II

Mark II and III

Ten centimetre Oboe, which was first used operationally in the autumn of 1943, presents a very complex historical story, as there were many technical variations in the equipments. The Mark II equipment was designed to work in exactly the same manner as the Mark I, in that one pair of ground stations worked with one aircraft at a time (the radio frequency being 10 centimetres as opposed to 1¼ metres). On the radio side there were three forms of airborne equipment known as Penwiper, Fountain Pen and Album Leaf. The first two were of low power and were rapidly superseded by the Album Leaf equipment which became standard. The aerial system in the aircraft originally consisted of a system of paraboloids, but this was later discarded in favour of a slotted wave guide which gave a wider beam and so more tolerance in 'Direction finding' the ground station from the aircraft.

On the ground side the system was to differ from the Mark I system in that the modulations were to be sent out by 'width' modulation (in which the pulse width was varied) as opposed to 'space' modulation (in which the distance between two successive pulses was varied). In addition, the whole console in the ground station was to be re-designed, the direct factors effecting operational results being that, the method of sending out the automatic modulation was different and that the 'Mouse' system for measuring the ground speed was of the 'instantaneous velocity' type. (Details of the effects of this new 'Mouse' are discussed in greater detail below). In addition, the whole console was designed with a view to improving the accuracy of range measurement to less than 0.01 statute miles. The Mark III equipment was to use the same type of console, but one radio channel was to work several aircraft simultaneously, this being achieved by the use of different P.R.Fs which were sorted out by a special filter (Filter 166) in the aircraft in a similar manner to the way in which the Mark I type filter (Filter 68) separated the navigators' signals from the pilots'.

On the ground station side this scheme was considerably modified. The first Mark II stations (known as the IIF. stations) used the Mark I type console and modulations with a Mark II radio equipment, as the full

/Mark II

Mark II type consoles were not fully developed. As a further interim measure some similar stations (known as the IIS.M.) were built in trailers as a forerunner of the final version of the Mark II - the Mark IIM. The Mark IIMs (the first of which was operational just before D-day) included all the Mark II devices. Owing to technical and operational difficulties the Mark III scheme was eventually given up and the Mark III stations were operated with one console using one radio equipment. The scheme of using multiple P.R.Fs was, however, successfully operated - several Mark IIM or modified Mark III stations working on the same radio frequency simultaneously but on different P.R.Fs.

Trials on Accuracy and Reliability

During the winter of 1943/44, small scale trials were conducted. To determine the accuracy a small number of bombs were dropped on bombing ranges and these results were analysed, chiefly with a view to ensuring that there were no gross errors in the Mark II system. These trials later developed into the far more extensive trials conducted in the pre D-day period which are described below. Frequent experimental attacks were also carried out to test out the reliability of the various forms of Mark II equipment. O.R.S. Pathfinder Force produced a weekly summary of these operations indicating the cause of the failures where known. This work was later taken over by a No. 60 Group Liaison Officer who was attached to Headquarters No. 8 (P.F.F.) Group at the instigation of the O.R.S., and who spent his whole time investigating failures in detail.

Repeaters

In order to increase the range of Oboe a system was formulated whereby a 'repeater' aircraft would fly between each ground station and the target and so relay the signals between the aircraft and ground station. Experimental operations were conducted using Mark I equipment in the autumn of 1943. Some bombs were successfully dropped on Emden using 'single leg' repeater. Considerable work on the eventual design of a Mark II repeater was also carried out during this period and the O.R.S. assisted in this. Owing, however, to the pressure of other

/commitments

commitments, the repeater scheme eventually lapsed and no further operations or experiments took place.

Effect of Propagation

An attempt was made during the winter of 1943/44 to determine the effect of propagation conditions on the range of Oboe. Arrangements were made to receive Meteorological Office forecasts of the propagation conditions expected in front of the Oboe ground stations. It was found, however, that during the winter these conditions varied very little indeed. Any effect of propagation was completely masked by the big variation, the cause of which was often untraced, within the Oboe system itself. Although the propagation conditions undoubtedly varied (and improved) considerably in summer, no correlation could be established. There was, however, an improvement in range and reliability in the summer months which may have been due partly to this cause.

Use of Oboe by other Commands

In the autumn of 1943, the Eighth U.S. Air Force installed Oboe in some of their aircraft and attempted to use it operationally. Some considerable difficulty was at first experienced, due chiefly to operational teething troubles. Owing to its limiting range at their operational height and their desire to concentrate on H2X for long range work, the decision was taken to discontinue these experimental operations.

When the Ninth U.S. Tactical Air Force was formed in the period before D-day, Oboe was fitted to a few of its aircraft. Practice and experimental flights then quickly gave way to operations, and eventually in the D-day and post D-day periods a high proportion of the Ninth Air Force sorties were carried out in formations led by Oboe aircraft (all using the R.A.F. ground stations manned by R.A.F. personnel). A considerable number of reports have been produced by O.R.S. IXth Bomber Command on these test and operational flights.

No. 2 Group, after it had been transferred to A.E.A.F. for tactical support work in early 1944, conducted a series of experimental operations in conjunction with No. 8 (Pathfinder Force) Group. Oboe Mosquitos of No. 109 Squadron led small formations of No. 2 Group aircraft on a limited number of sorties which were designed to provide the maximum amount of information on the effectiveness of this form of attack.

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These sorties were analysed in great detail by O.R.S. A.E.A.F., with the assistance of O.R.S. Bomber Command, and the results are given in O.R.S. A.E.A.F. Report No. 19 (No. 2 Group Oboe-led Missions). Although this report clearly showed that such attacks were considerably more effective than similar Gee-H attacks, it was decided to concentrate on the Gee-H method in view of its greater availability and tactical freedom, and the use of Oboe was discontinued.

Oboe for D-day

Bomber Command was assigned the task of knocking out ten coastal batteries on the Normandy coast on the night of D minus one/D-day. Owing to the fact that no flares could be used and that identification of the batteries at night would be extremely difficult, the batteries had to be marked blindly by Oboe and then bombed by the main force. In addition, Oboe was to be used extensively for the large bombing programme as a preparation for D-day and for the post D-day support for the army. These commitments required a high order of accuracy and reliability for Oboe, and intensive work was initiated early in 1944 to ensure that the highest possible accuracy was obtained. The work was co-ordinated by a member of O.R.S. Bomber Command who was attached to Headquarters No. 8 (Pathfinder) Group. In addition to the investigations into accuracy which were continued well beyond D-day, the work for D-day involved some special tasks. Considerable problems arose over the siting of the available Oboe equipment to provide adequate coverage for the D-day period commitments. The O.R.S. assisted in providing coverage diagrams for the stations, taking into account the horizons at the stations, and in working out the best possible combinations of stations to be used in any given area. By D-day there were stations near Cromer, Yarmouth, Beachy Head, Swanage and Lands End, and with equipments of various kinds the Normandy beaches were covered by five channels (two Mark I and three Mark II).

In order to assist in the accuracy and reliability investigations some personnel were lent to the O.R.S. by T.R.E., to act as scientific observers. These scientific observers were stationed at each ground station and reported back to the O.R.S., where their work was co-ordinated. The investigations of the O.R.S. were greatly helped by the attachment of these scientists.

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As planned, Oboe was very extensively used during the assault period. The most important commitment of marking ten coastal gun batteries on the eve of D-day was successfully carried out. There is no evidence of the actual accuracy achieved, but the gun batteries attacked provided only negligible opposition to the seaborne forces. In other operations before and after D-day Oboe played its part. In particular, it was used as the primary method of marking for the attack on communications in which the rail facilities communicating with northern France were systemmatically disrupted. Each operation was carefully analysed and the results of 15 of these attacks are summarised in Bomber Command O.R.S. Report No. S.159.[1] As experience in this form of precision attack was gained the technique was modified from simple blind ground marking to a more complex form in which the Oboe markers were dropped before the main force started to attack. These markers were then assessed and often augmented by markers dropped visually by a master bomber who directed the attack. On D-day itself, however, and in the attacks on gun batteries and other coastal targets just prior to D-day, the method was similar to that used in the Battle of the Ruhr - blind Oboe marking, with the main force bombing the centre of those markers.

Oboe after D-day

Night Attacks

Immediately after the landings in Normandy, the use made of Oboe did not appreciably change so far as attacks at night on army support targets were concerned. In general Oboe was used to drop markers before the main raid opened, and these markers were assessed and augmented by a master bomber who gave instructions to the main force. Similar methods were used at night in the attacks on V-weapon sites which absorbed a large part of Bomber Command's effort in this period.

Daylight Attacks

It was not long before Bomber Command started bombing short range targets in daylight, and as the Luftwaffe became weaker and the land forces advanced, the scale and range of these daylight attacks was gradually increased. The problem of controlling and marking for a daylight attack was rather different from that at night, and resolved

(1) A.H.B./IIH/241/22/14.

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itself into two problems - the initial finding of the target and the controlling of the attack after the target had become covered or surrounded by smoke arising from the attack. It was found that target indicators dropped blindly by Oboe were of great assistance in finding the target - particularly in broken cloud or hazy conditions or where the target was inadequately provided with recognisable landmarks. In general, therefore, in all daylight attacks Oboe was used to drop initial markers before the main attack opened. These were then often supplemented by visually aimed markers, and the attack was then directed by a master bomber. The initial markers naturally rapidly became obscured by smoke, and the master bomber would then give aiming instructions relative to the smoke. This method was used without major modification from the start of the daylight attacks until the end of the war. It was very successful in the many close support attacks carried out just in front of the line - as between Caen and Falaise, and later during the enemy offensive in the Ardennes in December 1944.

<u>Formation Attacks</u>

The flying bomb sites situated in northern France were within Oboe range at heights between 10 - 20,000 feet. It was thus possible to bomb them by Oboe using normal heavy bombers (Lancasters or Halifaxes). With this end in view, a few Lancasters were fitted with Oboe and held in readiness should they be urgently required. Various methods of using Oboe for bombing through cloud were considered. It was estimated that direct Oboe bombing would be about three times as effective (per ton of bombs detailed), and small formations of six heavy aircraft about twice as effective per ton of bombs detailed as the visual marking methods then in use. These methods could be used under weather conditions when normal methods were impossible, but on the other hand they were limited to relatively small numbers of aircraft. In view of the accuracy which could be achieved, however, this was not considered a great disadvantage for small targets like flying bomb sites.

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On the basis of this a considerable number of formation attacks were attempted during July. A note entitled 'Preliminary Note on Experimental Attacks in Crossbow Targets using Oboe-led Formations - July 1944'(1) was produced by O.R.S. Pathfinder Force summing up the evidence on the effectiveness of this form of attack. Although the evidence was scanty the original estimate was largely confirmed and this method was shown to be considerably more effective than normal methods. This was confirmed by crater counts and similar analyses (see Bomber Command O.R.S. Report No. B.219),(2) which showed that these Oboe formation attacks were 2.85 times as efficient as Oboe ground marking attacks, the next most accurate system of radar bombing.

When the breakout from Normandy occurred, and as the attacks against the flying bomb sites and facilities were discontinued, formation Oboe bombing was no longer required. On a few occasions, however, in view of the high efficiency of the methods, further attempts were made to use it. Mosquitos were occasionally used to lead small formations of other Mosquitos on further precision targets. A note was produced by O.R.S. Pathfinder Force in December 1944(3) showing what effort would be required to use this method to keep the oil targets in the Ruhr inoperative. It was shown that this method was quite feasible and that each Mosquito sortie would be roughly equivalent to a sortie by a heavy aircraft using normal methods. The method was, however, only used on a very few occasions, due chiefly to the lack of fighter cover.

In Bomber Command O.R.S. Report No. S.216,(4) it was pointed out that Delta Oboe would be of special advantage in formation flying, not only in increasing accuracy but also in providing many tactical advantages such as greater ease of formating on to track etc.

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(2) A.H.B./IIH/241/22/14.
(3)
(4). A.H.B./IIH/241/22/14.

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Unfortunately, however, the Delta system had not been completely installed when hostilities against Germany ended, and could therefore never be used with Oboe-led formations.

Continental Oboe Stations

Although the home ground stations had provided adequate cover over the Continent for the Battle of the Ruhr and later for the D-day and post D-day commitments, plans were laid at an early stage for the setting up of ground stations on the Continent. Bomber Command O.R.S. Memo M 154 entitled 'Notes on Plans for Oboe Mark II and III'(1) was written in July 1944 on this subject. The overseas ground stations were intended not only to increase the depth of Oboe cover, but also to enable attacks to be carried out at much lower heights and better angles of cut than was possible on similar targets when using the home stations. The first overseas stations were eventually installed at Commercy and Florennes and became operational by 26 September 1944. Each station consisted initially of two Mark IIM convoys on channels 11B and 13A. In October 1944, a third Oboe station was sited near Laroche. It had at first been thought that telephone facilities were essential between ground stations, but conditions behind the advancing armies made this impossible. Emergency mobile W/T stations were therefore provided and a technique worked out for their use.

A visit was paid by a member of the O.R.S. in October 1944 to inspect the overseas ground stations. As a result of the above visit, the O.R.S. were able to make several recommendations towards improving the operational and technical functioning of the stations. In addition, considerable assistance was given in the development of the complicated W/T system necessary for communication between the mobile ground stations during operations.

The change over from home to overseas ground stations continued with the addition of new stations at Rips, Molsheim and later at Tilburg in February 1945, by which time there were six ground stations fully operational on the Continent. In addition, all stations were gradually extended to four channel working. Only Winterton and Hawkshill Down remained in operational

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use in this country. In April 1945 these home stations controlled only 32 out of a total of 569 Pathfinder Force sorties. Throughout these developments the O.R.S. assisted in choosing the most suitable locations for the stations, taking into account the targets for which they were most likely to be used. During the final break through of the Allied forces in Germany, the ground stations were continually being moved forward, and in the closing stages of the war Oboe cover extended from Berlin in the north to east of Munich in the south.

Jamming of Oboe Mark II

The jamming of Mark I Oboe which began in the autumn of 1943 has been described on page above. On 1 February 1945, evidence was obtained for the first time that the enemy were jamming Mark II Oboe. Mark II and Mark III Oboe working on centimetre wavelengths had been immune to the ordinary Mark I jamming which operated on the 1½ metre waveband. This Mark II, jamming, however, was experienced in no less than four different forms and was on the whole much more subtle than the ordinary Mark I 'noise' jamming. Within the next few weeks reports of jamming came in from other channels (12, 11C and 11B) though throughout the most interference was experienced on Channel 12. Research into the nature of the jamming was carried out by Headquarters No. 60 Group, mainly with a view to devising possible countermeasures should the jamming become more serious. In the short period in which it was in operation, however, the jamming never had a very serious effect on operations. For example, between 1 February and 30 April 1945, out of 1,693 successful sorties made by No. 8 Group and the Ninth U.S. Air Force, only 145 reported interference and altogether only 22 failed due to this cause.

Oboe Computing Section

During the D-day period it was found that the number of targets attacked in one night was frequently so great that difficulty was experienced by the controllers in finishing the calculation of the target settings. This led to rushed work and a danger of gross error. In July 1944, plans for the formation of an Oboe computing section at Headquarters Pathfinder Force were therefore put forward by the O.R.S. This computing section, which consisted of W.A.A.F. personnel under a mathematician from the A.W.A.S., was fully trained by 1 September 1944. The section proved

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a considerable success from the beginning, and greatly eased the burden of the Oboe controllers and appears to have obtained a considerable reduction in the percentage of computational errors.

The Close of the European War

During the closing months of the European War, the number of Oboe sorties per month had risen to a maximum surpassing even the effort after D-day. Thus, in March 1945, the total number of sorties flown by No. 8 Group Oboe aircraft was 551, compared with 448 in June 1944. In addition to the No. 8 Group sorties, the ground stations had to handle a total of 471 sorties flown by the Ninth U.S. Air Force, making a total of 1,022 sorties for the month. The majority of these sorties, were engaged on normal ground marking. In spite of the scale of this effort, Headquarters Pathfinder Force were able in February 1945 to divert some effort to carry out bombing trials with Delta Oboe.

In concluding this account of the operations, it is of interest to record that in addition to its use as an aid to bombing, and in this Oboe proved to be of outstanding success, it was used in the closing days of the war in Europe to mark the reception areas for Operation Manna, the dropping of food and supplies for the relief of Holland. Needless to say the areas were well and truly marked.

The Accuracy of Oboe

The work which has been carried out on Oboe accuracy falls into three main categories :- (a) the determination of the fundamental radar accuracy of the system (ie. the fixing accuracy), (b) the determination of the bombing accuracy and of the magnitude of the various factors affecting it, (c) the determination of the operational accuracy. These are discussed separately below.

Fundamental Accuracy and Calibration

In measuring the range of an Oboe aircraft from the ground station, an allowance had to be made for the delay (the 'Peacock' delay) of the airborne Oboe equipment in receiving and re-transmitting the pulses from the ground stations. The calibrations of the system involved the determination of this delay together with the determination of the magnitude of any other factors affecting the accurate measurement of the range of the aircraft.

/Camera

Camera Obscura and Bombing

Initially, this calibration was performed by T.R.E. by flying an aircraft over a camera obscura. In addition, the delays so found were checked by actual bombing trials. The use of actual bombing results in determining the calibration of the system was, however, not found satisfactory except as a check on the approximate value, as the random errors were too great and factors such as the wind were capable of introducing local systematic errors which varied from day to day. Nevertheless, all bombing results were always analysed to determine whether the calibration was in any way at fault. In particular, during the early introduction of Mark II it was frequently necessary to obtain a quick approximate calibration by this means, and during the extensive bombing trials prior to D-day the delay figures obtained by bombing were compared with those obtained by other means. In a similar manner the actual operational results discussed in greater detail below were always used to check the calibration of the system, but were only sufficiently accurate to show up any large calibration errors.

Gun Layer (G.L.) Calibration Tests

At the first meeting of the Oboe Accuracy Committee under the chairmanship of the O.R.S., the results of the calibrations carried out up to that time (September 1943) were reviewed. These consisted principally of bombing results at short range and low altitude (10,000 feet) together with a few camera obscura results and some operational results of very questionable reliability. The meeting recommended the use of a G.L. apparatus to carry out an extensive calibration trial at operational height and range. It also recommended some further ground tests. A G.L. was obtained and sited at Clee Hill, and an important series of tests was laid on. These were greatly accelerated and expanded when the Oboe commitment for D-day became known. The results of the G.L. tests, which were analysed by the A.W.A.S. in a series of reports, were discussed at a further meeting of the same committee on 25 January. The tests were continued up to D-day and formed the basis of the delay figures actually used.

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This work, and that carried out at the ground stations, brought to light various shortcomings of the system. In particular, it was found that the calibration varied with the signal strength. In conjunction with Headquarters No. 60 Group, the variation of signal strength was examined and recommendations were produced on the best method of reducing this variation to a minimum. In addition, all the ground stations were examined and calibrated individually by No. 60 Group, but eventually it was decided that the differences between them could be neglected.

Results of Calibration

The results of these trials and of the practice bombing carried out concurrently are given in Bomber Command O.R.S. Memo M151 'The Accuracy and Reliability of Oboe'[(1)] which summarised the pre-D-day work on Oboe accuracy. Further details of the calibration programme may be obtained from two other memos issued by Bomber Command O.R.S. M152 'Note on Oboe Investigation No. 1'[(2)] and 'Interim Report on Oboe Accuracy Investigations',[(3)] and also from the minutes of the meetings of the Oboe Accuracy Committee. These trials provided a calibration which was considered sufficiently accurate for normal purposes, as the systematic radar errors were reduced to a small fraction of the random errors produced by other causes. After D-day, therefore, work on the calibration of the system tended to lapse and all efforts were turned to a reduction of the random errors and the elimination of gross errors.

Bombing Accuracy

The second stage in the study of Oboe accuracy was the determination of the actual bombing accuracy together with the factors affecting it. One of these factors was the radar fixing error discussed above, which was reduced to a relatively unimportant magnitude by the pre-D-day work on it. Previous to this, however, the radar error had not been separated out from the other factors and little was known about the relative importance of the various factors. The work done to determine the overall bombing errors and to elucidate its various causes is discussed in detail below.

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/Practice

Practice Bombing

The first Oboe accuracy trials were carried out by T.R.E. in April and May 1942, using a Wellington aircraft flying at 10,000 feet and gave an average radial error of 140 yards. After this there were numerous training flights in which bombs were dropped from Oxford aircraft from 10,000 feet, but few bombing results by experienced crews at normal operating heights were available until the intensive trials were carried out prior to D-day. These gave an average error from 28,000 feet or 275 yards, and of about 200 yards from 12,000 feet. These trials are discussed in the papers produced on the pre-D-day investigations. Later bombing trials were also carried out, but in most cases these were conducted to determine the improvement produced by various modifications to the system, such as Delta-Oboe. They are fully discussed in Bomber Command O.R.S. Report No. S.236 entitled 'A Survey of Oboe Accuracy'.[1]

Operational Bombing Trials

Some information on the bombing accuracy of Oboe was also obtained from various controlled operations specially designed to provide such information. In general such attacks were primarily designed to serve as a check on the overall working of the Oboe system and to ensure that no errors had been made in, say, the siting of the Oboe stations. Although such trials provide some of the data in operational accuracy and are considered under that section below, they were more in the nature of special practice bombing trials and are therefore discussed here.

In the early days of Mark I Oboe several calibration attacks were carried out, the most notable being that on Lutterade in December 1942, and shortly afterwards that on Florennes. These are analysed in Bomber Command O.R.S. Report S.78[2] but were inconclusive. There were also various further inconclusive trials against objectives in Germany which are outlined in Bomber Command O.R.S. Report No. S.102.[3] Before D-day, however, several more of these calibration attacks were launched,

(1) A.H.B./IIH/241/22/14.
(2) A.H.B./IIH/241/22/14.
(3) A.H.B./IIH/241/22/14.

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two of which are described in detail in Bomber Command O.R.S. Report Nos. S.~~200~~ 123[1] and S.~~217~~ 127[2]. Virgin targets were chosen and photographs obtained as soon after the attack as possible. The targets consisted chiefly of railway junctions or flying bomb sites. The overall accuracy of the new stations on the south coast was checked by this means, but the number of results was in general insufficient to provide a reliable basis for analysis. The random errors were found to agree reasonably well with the practice bombing results, but there were some apparent systematic errors which appeared to be caused by ballistic inaccuracies.

Investigations into Factors Affecting Bombing Accuracy

The operational and practice bombing results obtained in the beginning of 1944 made it clear that the operational accuracy of Oboe was still far short of what was theoretically attainable as set out in T.R.E. paper L/M31/S.E.T. and elsewhere. The O.R.S. were therefore asked to carry out a full-scale investigation into the causes of Oboe errors. This investigation was one of the main items in the pre D-day drive to increase Oboe accuracy. An interim summary of the action taken as a result of the above investigations was given in a paper on Oboe accuracy issued jointly by the O.R.S. and Deputy Directorate of Science. A complete report of the investigation was given shortly after in a paper submitted to SACRA on 22 June, entitled 'The Accuracy and Reliability of Oboe'. In this report it was considered that aircraft flying inaccuracies (weaving, height and airspeed variations) and wind drift of target indicators were the controlling factors in the marking accuracy of Oboe. Accordingly, in August 1944 a programme of research was instituted by Bomber Command O.R.S. to establish the magnitude of these factors and, if confirmed, to take steps to reduce them.

The investigation carried out was an extensive one. Type 'U' Recorders were fitted into several Oboe Mosquitos to obtain records of the aircraft instruments and the resultant films were analysed to

(1) A.H.B./IIH/241/22/14.
(2) A.H.B./IIH/241/22/14.

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determine airspeed and height variations. Track records of the path followed by the aircraft were obtained from the ground stations after operations, and were analysed to determine the aircraft's average heading error and distance off track at the moment of bomb release. Calculations were next made to determine the effect of these average flying errors on the bombing accuracy at different heights and angles of cut and with different systems of Oboe 'Mouse'. An attempt was made to confirm these figures by sub-dividing the operational results, but unfortunately there was insufficient evidence for the results to be conclusive. Analyses of the discrepancies between the met wind and the found wind were carried out over a considerable period, and from these were calculated the average Cross Trial and Flare Drift errors of target indicators due to errors in met wind predictions.

An interim report on the investigation was issued in October 1944, and a complete summary later was given in Bomber Command O.R.S. Report No. S.202.[1] Comparison of the estimated magnitudes of the principal sources of error with the operational accuracy showed that there were now no unexplained sources of error in Oboe. The evidence confirmed the estimates that flying errors and flare drift of high burst target indicators candles were the major sources of the error in the system. Recommendations were therefore made for the introduction of Delta-Oboe to reduce flying errors and for the use of low burst target indicators wherever tactically possible.

In September 1944 the data obtained on average flying errors was handed over to A.W.A.S. to be evaluated independently. The results of their findings, published in April 1945 in A.W.A.S. Report No. 58,[2] were in good agreement with the earlier calculations by Bomber Command O.R.S. In March 1945 an analysis of track records was carried out by O.R.S. Pathfinder Force to determine if any change in the standard of flying had taken place. The results showed a slight reduction in the average

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(1) A.H.B./IIH/241/22/14.

(2) "A comparison of the extent to which flying errors vitiate the performance of various mousing signals."

/heading

heading error, but otherwise little change in the standard of flying with non-Delta-Oboe since the investigations in the autumn of 1944 (Bomber Command O.R.S. Memo No. M).(1)

Operational Accuracy

1942 to D-day

When Oboe was first used operationally in December 1942, an investigation was immediately carried out. The results of this first investigation, covering all raids in the period 20 December 1942 to 17 January 1943, are given in Bomber Command O.R.S. Report No. S.78. This report dealt with the bombing and skymarking attacks in the period and made many recommendations on operational details in the light of the experience gained on these first operations. The accuracy of Oboe bombing appeared to be of the order of 650 yards, but there were indications of several gross errors.

From early 1943 Oboe was used extensively for marking targets for the main force. For this purpose target indicators were used and a large part of the analysis of Oboe operational accuracy was concerned with determining the position of these T.Is, and in analysing the results to elucidate the causes of errors. A technique using night photographs was gradually developed and formed the basis of all the work of this nature. The first report, giving details of this work, was Bomber Command O.R.S. Report No. S.102 (2) which described the operational use of Oboe, including the first ground marking raids up to June 1943. The average accuracy in this period appeared to be approximately a quarter of a mile, and was therefore little different from that given in the previous report. A systematic bias of approximately a quarter of a mile was, however, revealed.

During the winter 1943 Oboe was not used extensively for marking, and little information on marking accuracy became available. However, as described above, Report No. S.123, (3) describing the Oboe bombing attacks on a special military construction between 29 December 1943 and 5 January 1944, gave details of the bombing accuracy in a special calibration attack. The 50 per cent circle of the bomb pattern about the M.P.I. was 260 yards, a considerable improvement over previous bombing results. This analysis and the results of further bombing raids carried out on 27 and 29 January 1945 (see Report No. S.127 (4) showed, however, that further alterations in the

(1)
(2) A.H.B./IIH/241/22/14.
(3) A.H.B./IIH/241/22/14.
(4) A.H.B./IIH/241/22/14.

/'Peacock'

'Peacock' delays of the system were necessary. The correct value for the ballistic corrections necessary with the 500 pound general purpose bombs in use was also determined.

In early 1944 Oboe was used as the primary method of marking for the Railway Plan, in which the Command was assigned the task of attacking the repair facilities of a number of marshalling yards in France, Belgium and western Germany. These attacks were the subject of a series of reports by the O.R.S. A summary of fifteen of the attacks between 6 March and 11 April 1944 was given in Report Nos. S.159 (1) and S.167. (2) A description of the technique employed was given in Report No. S.154. (3) Most of the targets were at short range and the Oboe sorties were carried out at moderate heights and favourable angles of cut. The analysis showed that there was an alarmingly high percentage of gross error, but apart from this the accuracy of the Oboe marking was approximately 330 yards, This was of the order expected when the O.R.S. had planned the force requirements for these raids.

In April to May 1944 a series of 14 Oboe missions was carried out by No. 2 Group (led by No. 8 Group Oboe aircraft). A report written by O.R.S. A.E.A.F. (O.R.S./A.E.A.F. Report No. 19), (4) assisted by Bomber Command O.R.S., summarised the results of these formation attacks which again showed a low average error but a high proportion of gross errors. Bomber Command O.R.S. Report S.164 (5) dealt with Bomber Command Oboe ground marking attacks on ammunition dumps in the same period. One of the final roles of the Command before D-day was the attacking of gun sites on the French coast between Cherbourg and the Belgian frontier. These attacks were carried out by means of Oboe ground marking. The accuracy of the Oboe marking was the subject of Report No. S.158. A summary of the

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(1) A.H.B./IIH/241/22/14.
(2) A.H.B./IIH/241/22/14.
(3) A.H.B./II/69/231(B)
(4) A.H.B./IIM/A49/1K (App.No.26).
(5) A.H.B./IIH/241/22/14.

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information obtained on Oboe marking accuracy between 6 May and 6 June 1944 was given in a Bomber Command O.R.S. paper (Oboe Serviceability and Accuracy), which summarised the performance of Oboe in the final month of the intensive drive to increase Oboe accuracy before D-day.

Gross Errors

All these investigations led to a considerable drive to determine the causes of gross errors which were considered to be one of the most serious shortcomings of the system. This work led to a tightening up of many of the procedures at the ground stations and in the aircraft. Some of the possible causes of gross error were eliminated. Thus, the method of detailing the aiming points using photographic cover was found to have caused several errors and a change in procedure eliminated this. These gross errors were also one of the reasons for the introduction of the Oboe Computing Section in that it enabled the controllers to spend more time in checking the equipment itself. The fact that these gross errors were most frequently releasing errors led to a detailed investigation of the working of the mouse and the discovery of several sources of errors which were eliminated.

D-day to the close of the European War

The first data on the operational accuracy of Oboe after the pre D-day drive, was from the target indicator plots for June 1944, described in Report No. S.180. This report showed that the average radial error of low burst target indicators dropped from 24,000 feet had been reduced to 212 yards. The percentage of gross errors had also fallen from approximately 20 per cent in the previous analyses to 13 per cent in June 1944. No significant systematic line error, i.e. across track, was discovered either in these or subsequent plots, thus confirming that the delays determined in the calibration tests and trials were now adequate. The elimination of systematic range errors took longer because ballistic problems complicated the issue. A description of this work on target indicator ballistics is given below.

Between June 1944 and the end of the European War, very few further technical changes were made to the system. In this period the O.R.S. were able to carry out detailed investigations into the operational accuracy of

/Oboe

Oboe under various conditions with high or low burst target indicators and using the home or the overseas ground stations. Bomber Command O.R.S. Reports Nos. S.182 (1) and S.191 (2) dealt with day operations between August and October 1944 on targets in occupied territory using high burst T.Is. Report No. S.201 (3) dealt with night operations between July and November 1944 using similar high burst T.Is, but on Ruhr targets at great heights and small angles of cut. T.I. plots obtained in the periods November 1944 to March 1945, and March to April 1945, were the subject of two memoranda issued by O.R.S. Pathfinder Force. These memoranda dealt with the accuracy of Oboe marking in raids controlled by the overseas and the home ground stations. All the above results were summarised in Bomber Command O.R.S. Report No. S.236. (4) This report analysed as a whole the considerable data on Oboe accuracy obtained during the last year of its operational use, from June 1944 to May 1945, compared the latest accuracy with earlier results, and estimated the main causes of error still remaining in the Oboe system.

Special Investigations ~~since~~ after D-day

Ballistics of Target Indicators

The plots of T.Is prepared by the Central Interpretation Unit from night photographs were of considerable value to the O.R.S. in helping to eliminate errors due to the performance of T.Is. Examination of the photographic evidence used in preparing Bomber Command O.R.S. Report No. S.180 (5) of T.Is dropped in June 1944 showed that sticks of T.Is were often very split up on the ground, presumably due to ballistic instability and interference between T.Is dropped in too close a stick spacing. To eliminate the latter source of error, recommendations were made to alter the order of release of T.Is from the aircraft and to increase the stick spacing to 0.3 seconds. These recommendations were put into force on 24 June 1944, and photographic evidence showed that since that date the 'splitting' of sticks of T.Is was considerably reduced.

(1) A.H.B./IIH/241/22/14.
(2) A.H.B./IIH/241/22/14.
(3) A.H.B./IIH/241/22/14.
(4) A.H.B./IIH/241/22/14.
(5) A.H.B./IIH/241/22/14.

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The elimination of systematic radar errors by the pre D-day calibration programme enabled T.I. plots to be used in eliminating systematic ballistic errors. It was discovered by the O.R.S. that the wrong terminal velocity (T.V.) for the T.I. was in use. When the ballistic tables had been corrected, no further systematic errors were discovered in the Oboe system.

Instantaneous Velocity Mouse Performance Tests

In October 1944, during the visit of a member of the O.R.S. to the overseas Oboe ground stations, it was discovered that the Instantaneous Velocity (I.V.) 'Mouse' installed at all Oboe Mark III and Mark IIM ground stations was frequently unstable, and that the daily tests then in use did not give any indication of the actual bombing error which this instability might cause when the Console was in operational use. In addition, operational results had frequently given rise to the suspicion that the 'Mouse' was causing serious releasing errors. Experiments were carried out by Bomber Command O.R.S. at the home ground stations during November and December 1944, to devise a suitable test for the I.V. 'Mouse' and to determine the approximate magnitudes of the errors which it was causing. In December 1944, a meeting was called to discuss these findings and, as a result of Bomber Command O.R.S. recommendations, several modifications were made to ground station procedure. The existence of the errors in the I.V. 'Mouse' was also confirmed and, as a result, the 'I.V. "Mouse" Overall Performance Checks' (as they came to be called) were adopted as a standard test to be carried out daily, subject to operational commitments, at all the Oboe Mark IIM and III ground stations. As a result of the tests many of the causes of error in the I.V. 'Mouse' were revealed, and subsequently reduced or eliminated. Details are given in Bomber Command O.R.S. Report No. 223.(1)

Average Velocity versus ~~I.V.~~ Instantaneous Velocity 'Mouse'

The theoretical work on the effect of flying errors in Oboe accuracy (see Bomber Command O.R.S. Report No. S.202)(2) had shown that under many conditions of height and angle of cut the I.V. 'Mouse' was less accurate

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(1) A.H.B./IIH/241/22/14.
(2) A.H.B./IIH/241/22/14.

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than the Average Velocity (A.V.) 'Mouse'. At the instigation of Bomber Command O.R.S., an A.V. Mouse computor was designed for fitting into Oboe Mark IIM and Mark III stations for use as an alternative to the standard I.V. 'Mouse.' This trial installation was inspected by representatives of Air Ministry, T.R.E., Headquarters No. 60 Group, Headquarters Pathfinder Force and O.R.S. in January 1945, and it was agreed to adopt the modification. Shortly after this, however, T.R.E. issued a paper stating that, in their view, there were no grounds for the fitting of an A.V. 'Mouse'. This was answered by Headquarters Pathfinder Force in a paper entitled 'A.V. versus I.V. Mouse'. Headquarters Pathfinder Force did not consider that the arguments put forward by T.R.E. were sufficient to justify the advantages of having an alternative mouse, especially in view of the fact that the 'A.V.' Mouse was simpler and preferred by the controllers. Bomber Command O.R.S. reviewed the situation in Memo No. M.153 entitled 'A Review - A.V. 'Mouse' as an alternative to I.V. 'Mouse'[(1)], and summarised the arguments which had been put forward for and against the fitting of an alternative A.V. 'Mouse'. It was decided that there was no case for altering Headquarters Pathfinder Force's requirement for an alternative A.V. 'Mouse', and the installations were proceeded with at the ground stations. The O.R.S. assisted in laying down the conditions under which the A.V. 'Mouse' should be used in preference to the I.V. 'Mouse'.

Oboe Serviceability Investigations

During the summer of 1944 the serviceability of Oboe became established at 70 per cent to 80 per cent success in terms of aircraft bombing per aircraft despatched. During the autumn, however, this performance deteriorated, until in November and December 1944 less than 50 per cent of the aircraft despatched succeeded in bombing. By using the maximum number of available channels on all major marking raids it was possible to avert any complete failure of the Oboe marking, but none the less poor Oboe serviceability was on occasions causing breaks in the continuity of the marking. Such breaks often meant that the backers-up or the main force

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had no primary Oboe markers to bomb, with consequent loss in their accuracy. The responsibility for maintaining Oboe serviceability lay primarily with Headquarters No. 60 Group and with T.R.E. P.D.S. Section, but after November 1944 the O.R.S. assisted in determining the cause of this loss in reliability. Frequent meetings were held between representatives of O.R.S., T.R.E. and No. 60 Group to discuss the latest available data and to reach agreement on all debateable points before implementing the necessary decisions. In January 1945 a special section was formed at T.R.E. to continue the detailed analysis of causes of failure. In particular, investigations were carried out into the effect of poor propagation conditions and into the causes of the increase in non-Oboe failures. An analysis was also carried out by the O.R.S. into the accuracy of navigation of the Oboe aircraft to the waiting point where they were picked up by the ground stations. It was found that many failures were caused by aircraft coming up out of range or one or other of the ground stations. Another investigation was carried out to determine the correlation between experience of aircrews and their percentage success. In January 1945 the serviceability of Oboe commenced to rise again, and in April 1945 reached 70 per cent, the highest since August 1944. The home stations alone, working at very short range over Holland, achieved a serviceability figure of nearly 90 per cent.

Delta Oboe

Delta or rate-aiding Oboe was a device to simplify the task of flying on to and along an Oboe beam, and thereby to enable a more accurate run with less weaving to be made. In the Delta principle, the tracking station sent signals to the aircraft which took into account not only the distance of the aircraft off track but also its rate of approach to or away from the track. The system was arranged so that the pilot could obtain an equi-signal note anywhere within four miles of the track centre so long as his heading was correct, i.e. was towards the beam. In spite of these advantages, the modifications necessary for the use of Delta in Oboe Mark III and Mark IIM were comparatively small, and involved no changes in the airborne equipment.

/Recommendations

Recommendations for the development of the Delta principle had been made by the O.R.S. since early 1944, but partly because of other commitments T.R.E. were not able to have Delta fully developed and to carry out the necessary flight trials until January 1945. These experimental flights, most of which are described in the T.R.E. Memo 'The Application of Rate Aiding (Delta) to Oboe', revealed a considerable reduction in the average weaving errors of the aircraft. Bomber Command O.R.S. evaluated curves showing how this increase in flying accuracy would reduce the bombing errors. These curves also showed that although Delta would increase the accuracy under all conditions, the greatest improvement would be at great heights and small angles of cut and with the I.V. rather than the A.V. 'Mouse'. Under average operational conditions it was estimated that Delta would reduce the average bombing error due to flying inaccuracies from 240 yards to less than 150 yards.

As a result of the above estimates, it was decided that there was a definite requirement for Delta. After some trials by the Pathfinder Force which were analysed by the O.R.S. (see Bomber Command O.R.S. Memo M entitled 'The Results of Delta Bombing Trials')(1) the installation of Delta was started in all the Mark III and Mark IIM Oboe stations. Meanwhile, further investigations were carried out by Bomber Command O.R.S. into the effects of Delta on Oboe accuracy. The results of these and the earlier investigations were summarised in Bomber Command O.R.S. Report No. S.216.(2) The Delta modifications at the operational ground stations were not completed before the close of the European War, so no operational evidence could be obtained on the accuracy of Delta. The results of the Delta bombing trials later carried out by T.R.E. were, however, in complete agreement with the improvements estimated by Bomber Command O.R.S. in Report No. S.216, and fully confirmed the value of Delta Oboe.

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(2) A.H.B./IIH/241/22/14.

/ Losses

Losses and Damage to Oboe Aircraft

In concluding this account of the use of Oboe, it is of interest to record that from its introduction into operational use on 20 December 1942 to the end of the war, no less than sorties were flown by No. 109 Squadron over enemy territory. Not a single aircraft failed to return, no aircraft was attacked by enemy fighters, and the percentage of sorties damaged by flak was per cent. This is a very remarkable record even allowing for the performance of the aircraft concerned, for the enemy was ultimately able to plot and identify the Oboe aircraft, which he knew were leading the attack and they were flying at constant height on a steady course for as long as ten minutes in the target area.

CHAPTER 15

THE STUDY OF NIGHT BOMBER TACTICS

The study of Bomber Command's operations in order to determine the causes of losses and to seek ways and means of reducing them formed a large part of the activities of the O.R.S. The importance of the work was twofold. In the first place, it was essential to keep losses down to reasonable limits despite improvements in the enemy's defences in order that the offensive might be maintained. It was generally agreed that a 10 per cent loss rate was sufficient to stop a bombing campaign. Secondly, the lower the loss rate the quicker would the bomber force be built up to the strength considered necessary to achieve the objective of destroying the enemy's war potential.

At the instigation of Sir Henry Tizard a study was made by Mr. A.E. Woodward-Nutt of the losses sustained by Bomber Command to compare the effectiveness of the German defences with our own and to see if anything could be learnt from the experiences of our own bombers. The analysis was continued by Dr. B.G. Dickins, and in July 1941 a comprehensive report was issued reviewing the losses sustained over the period October 1940 to June 1941.

The report showed that the percentage of bombers intercepted by night fighters was definitely on the increase and that the estimated total number of sorties attacked had increased markedly since February 1941. The degree of success of these attacks while not capable of definite assessment, was thought to be about 30 per cent fatal to the bomber. An assessment of the causes of aircraft lost, based on crews' reports, intercepted wireless traffic and other circumstantial evidence, was found to support the conclusions drawn from the increase in fighter interceptions and attacks. It was pointed out that a further slight improvement in enemy technique would result in a considerable increase in the percentage of bombers intercepted, and consequently in percentage losses. In view of the subsequent development of aids to bomber defence, it is of interest to quote the following extract from the report :-

'...... It is clearly of the greatest importance to provide for this eventuality (i.e. the improvement in enemy technique) and, since the bombers' best defence probably lies in its ability to take avoiding action before the fighter has

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obtained visual contact, it is essential to develop a detector to indicate the approach of the fighter. This might be a simplified form of A.I., or might be based on the means used by the enemy to assist interception. Arrangements are already in hand to determine whether a radio or infra-red technique is being used, and once this has been established it is recommended that the development of suitable detectors should proceed on the highest priority. The development of a detector which is independent of the enemy's technique may, however, be considered preferable.'

A second report on similar lines was issued to cover July 1941, and the task of studying progress in the enemy's night fighter defence from the operational returns was then taken over by the Operational Research Section, ~~formed~~ at Bomber Command when it formed early in September 1941. From then on the publication of monthly reports on sorties, losses and fighter interceptions of Bomber Command aircraft in night operations became a regular feature. As more and better operational returns became available and the operations of the Command grew in scale and variety, the scope of these reports gradually became more comprehensive. In general, their aim was as follows:-

(a) To show the trend of losses and fighter interceptions in the light of current operational conditions.

(b) To record changes in bomber tactics and in the radio counter-measures employed as they occurred.

(c) To observe the corresponding changes in the enemy's tactical use of fighters as shown by the overheard wireless traffic and the incidence of night fighter opposition in individual operations.

(d) To discover the current methods of attack of the individual enemy fighters as evidenced by Combat Reports.

(e) To record major changes in the enemy flak defences or search-light dispositions.

(f) To provide monthly statistical summaries giving sorties, losses, enemy action damage and fighter interceptions according to aircraft types, types of operations, and target areas.

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These reports had a wide circulation and evidently filled a general need since, when they were discontinued for a short time owing to pressure of other work, many urgent requests for their revival were received. It was unfortunate that these reports, the purpose of which was to provide an up-to-date picture of the situation, gave the impression in certain quarters which did not receive our more secret reports, that Bomber Command O.R.S. concentrated mainly on statistical summaries of operations rather than their scientific analysis and study. In point of fact, while these reports supplied the basic statistics relating to bomber losses, they represented a very small proportion of the effort spent on this important subject.

While, as will be seen later, much effort was directed towards the study of such subjects as aircraft vulnerability and the need for radio countermeasures in support of bombing operations, these were in the nature of long-term investigations since it took a long time to incorporate modifications in aircraft and to develop the necessary R.C.M. equipment. The tactical employment of the bomber force was, however, entirely different since changes could be made immediately. Investigations into the effectiveness of the general tactics of the night bomber force therefore formed an important and continuous part of the work of the O.R.S. group concerned with research into the causes of, and methods for reducing bomber losses. The subject was an extremely complicated one since bomber losses varied considerably with the defences encountered <u>en route</u> to and at the target, with the weather, with the flying characteristics of the aircraft, with the experience and ability of the crew, with the special radar and other protective devices carried and with the radio countermeasures used. As the enemy defence system was continually changing and improving, it was necessary to keep the subject continually under review. As with other subjects, those working on the problem maintained a close liaison with the appropriate Air Staff branches, in particular with the Signals, Intelligence and Operations branches, with the other Operational Research Sections, especially O.R.S. Fighter Command and the Army Operational Research Group, and with the Technical Establishments of the Ministry of Aircraft Production.

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The data for the researches came from many sources. Intelligence Reports gave particulars as to the time, height of bombing, combats, sightings of enemy aircraft seen destroyed for each sortie, together with details of intercepted wireless traffic. Details of combats were obtained from special reports. Information on the density of our aircraft in space over enemy territory had to be obtained from detailed analysis of navigators' logs. Special equipments were placed in our aircraft in order to record the evasive action undertaken. Special experiments were made in order to be able to forecast the range of visibility of aircraft at different times of the year during the period of twilight. Such was the type of information which formed the background for the investigations, which were sometimes made on the O.R.S.'s initiative and sometimes at the request of the Air Staff. Studies were sometimes based on data obtained from past operations, and at other times possible new tactics were investigated from the theoretical point of view.

The subject of tactics is, of course, closely linked to the use of radio countermeasures, and some aspects of the problem have for convenience been dealt with in Chapter 17.

Concentration

When the O.R.S. was formed in September 1941, bombing operations were still in an elementary state. The forces available were small, they were usually detailed to a number of targets and the selection of routes was left to groups and squadrons. At the same time the enemy G.C.I. system of fighter interception was being established, and the need for modifying bomber tactics was being considered. In particular, the problem of the desirability of concentrating the bomber forces had been raised and was a subject of controversy, but so far no attempts had been made either to deduce the probable trend of losses with differences in concentration from the little operational data available or to put the proposal to practical test.

On 28 October 1941, the Air Staff requested the O.R.S. to examine any evidence available to discover whether concentration in time over targets did, in fact, lead to a reduction in casualties as against more drawn-out attacks. A rapid investigation was made on the subject, and Bomber Command O.R.S.

/ Memorandum

Memorandum No. 9 'Preliminary Note on the Relation between Concentration in Time over a Target and Bomber losses'[1] was issued three days later. The memorandum pointed out that contrary to the current view in the Command, the effect of concentration in time over target would be expected to have the effect of reducing the effectiveness of both the enemy controlled interception and of his predicted A.A. fire. The statistical evidence, based on the relation between losses experienced and duration of raid, which it had been possible to collect together in the short time available since the Air Staff's request, indicated that concentration in time was likely to lead to a reduction in losses. It was mentioned, however, that this would not necessarily be expected to hold on nights of much moon when cats-eye fighters would probably be used against our bombers. The paper concluded by saying that further investigations would be carried out immediately. It was suggested that a few experiments might be carried out in which a number of aircraft should attack a target in one period of, say, 30 minutes, followed by the same number of aircraft attacking the same target over a longer period. The Air Staff considered, however, that such experiments were undesirable. They felt that it was better to await the data which would become available as a result of analysis of routine operations.

A much more complete investigation was carried out and published in February 1942 in Bomber Command O.R.S. Report No. 29, entitled 'An Investigation into the Effects on Bomber Losses of Concentration in Time at the Target and Duration of Attack'.[2] It was again found that the percentage of aircraft missing tended to decrease as concentration increased, and it was recommended that the rate of arrival at the target should never be less than 50 raiders per hour when the moon was down, or less than 80 raiders per hour when the moon was high. It was pointed out that under the conditions then obtaining, much higher rates must be planned in order to achieve these rates. The Commander-in-Chief accepted the conclusions and gave instructions that they should be worked to as far as other factors allowed. The reason that the results when the moon was high indicated that a higher concentration was

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(1) A.H.B./IIH/241/22/3.

(2) A.H.B./II/70/369.

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desirable than when the moon was down was not explained, and it may well be that the success of catseye fighters was not appreciable at that time.

The matter was put to practical test in three one thousand-bomber raids made in May and June 1942. The bombers were planned to attack at the rate of ten per minute, and even though in practice the actual concentrations achieved did not quite reach the planned figure, they were still much greater than on any previous occasion. From the point of view of losses, the three raids provided some confirmation of the beneficial effects of concentration in time over targets, since in each case the actual loss rate suffered was smaller than would have been expected from previous experience on the same target and under otherwise similar conditions. These raids were, however, much heavier than any previously made, and the effect of the size of raid on the loss rate could not be taken into account. The routes followed by the aircraft of the different groups in these raids were not in all cases absolutely identical but they were, nevertheless, much closer together in space than had previously been customary, and the theory of concentration in space en route was therefore simultaneously given a provisional test.

The O.R.S. had, in the meantime, been investigating from previous operational returns the effect of concentration in space en route on bomber losses, and at the beginning of June 1942 a report on the subject was published in Report No. 34.(1) This drew the definite conclusion that losses decreased as concentration in space and time increased, and that this was particularly marked when the moon was down.

From June 1942 onwards, one target, against which practically all the available forces were used, was selected for each night's operation and co-ordinated plans for each attack, including a common route, were laid down at Command Headquarters. The planned concentration of bombing remained at ten aircraft per minute until September 1943.

The improvement in navigation, with corresponding improvement in time-keeping, brought about by the introduction of Gee, made the achievement of concentrated attacks a more practical proposition, and as time went on the actual concentration achieved approached more and more nearly to that planned.

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(1) A.H.B./II/70/163.

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A remarkable illustration of the correctness of the concentration policy and of the usefulness of Gee in enabling this policy to be carried out, was given in Bomber Command O.R.S. Report No. 74, 'An Investigation into the Effect of Gee on Casualties'.(1) This paper considered the loss rates of Gee and non-Gee aircraft, and found that the loss rate of Gee-carrying aircraft was 40 per cent less than that of non-Gee aircraft.

Although the policy of concentration in space and time recommended by the O.R.S. was accepted by the Command there was, at the beginning and, in some quarters, throughout the war, a widespread feeling that dispersion of bomber forces in time and space was more likely to result in low losses, and a large number of investigations were made into this subject, e.g. Bomber Command O.R.S. Memorandum No. M.122, 'Concentration in Time, March - July 1942'.(2)

In June 1943, in connection with investigations into the effective range of Gee, plots were made by the O.R.S. showing the position of the first Gee fixes obtained by aircraft on their homeward journeys. These plots showed that the concentration on the return route was often far from satisfactory, and that the bombers were liable to be considerably dispersed. The matter was brought to the notice of the Air Staff, together with a recommendation that a further drive to improve concentration should be made, primarily on account of the imminent introduction of new countermeasures whose success would largely depend on the achievement of good concentrations. This suggestion was adopted, and a note prepared by the O.R.S. was issued to groups as a Command Tactical Memorandum. The Memorandum recommended that navigators should obtain a Gee fix at the earliest opportunity after leaving the target (a range of 300-350 miles was possible), and that if they were off the prescribed route they should alter course by at least 45 degrees and increase speed until once more on track.

When Window came into use in July 1943 the tactics employed in heavy bomber operations at first remained unchanged, and the planned concentration of aircraft at the target was kept at roughly 10 per minute. However, after the first set-back caused by this countermeasure, which rendered the enemy

/G.C.I.

(1) A.H.B./II/39/1.
(2) A.H.B./IIH/241/22/3.

G.C.I. controlled fighter useless except against stragglers, the enemy quickly improvised an alternative fighter defence system employing large numbers of free lance fighters under a broadcast running commentary. The commentary gave height and direction of the bomber stream, the areas over which it was passing and the probable or actual target. The system involved the establishment of a network of radio and visual beacons all over Germany, which the enemy used for navigating his fighters to intercept the raid. The fighters were drawn from long distances during the early stages of the raid and large forces of fighters were used.

The operations between 9/10 August and 31 August/1 September, during which time the enemy's new method of employing his free lance fighters had been in full use, were analysed and the results issued in Bomber Command O.R.S. Report No. 80.(1) It appeared from intercepted traffic that the main object of the enemy was to get his fighters to intercept over the target and to follow the bombers on their homeward route. A theory which was borne out by the fact that aircraft in the earlier parts of an attack were less liable to be intercepted than those in the latter part, and that the great majority of interceptions took place at or near the target. While the method was clearly achieving some success, it suffered from the defect that unless the target could be identified promptly by the controllers, the fighters might be too late in arriving to make contact with the bombers. The report therefore suggested that erratic routeing and diversionary attacks should be employed to confuse the controllers, and that the concentration over the target should be increased, thereby increasing the bomber's chances of getting away from the target before the fighters arrived.

As a result of this report, the planned concentration at bombing was increased to 30 aircraft per minute as from 22/23 September 1943, erratic routeing and diversionary attacks at first made mainly by small forces of Mosquitos were instituted. The Mosquitos usually followed the main bomber route for most of its way before breaking away. In consequence of these steps the method of target interception proved extremely unreliable, and during the next 3 months bomber losses remained reasonably low.

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(1) A.H.B./IIK/46/468

In the next review of defensive tactics in night operations (Bomber Command O.R.S. Report No. 88) (1) covering the periods 3/4 September to 19/20 November 1943, it was found that the direct effect of the increase in concentration was obscured by the fact that all the less concentrated raids in the period had taken place on nights when diversionary attacks had been most successful in diverting the fighters from the main target. The analysis did, however, show that for raids lasting longer than 35 minutes, the missing rate was markedly greater than that for shorter raids, and also that the earlier aircraft in the bomber forces stood a much less chance of engagement by fighters than those attacking later. The obvious conclusion was thus still to keep raids as short as possible.

In recommending a further increase in concentration, it was realised that the chances were increased of a fighter sighting a bomber near the target or in the bomber stream once a fighter had found the stream. It was therefore very desirable to determine whether the increase in losses due to this fact was outweighed by the reduction caused by the shorter time over the target. A theoretical analysis was accordingly undertaken. The method used was to calculate the expected number of bombers a single fighter would be likely to destroy assuming certain probable visibility ranges of fighters on bombers and times for a fighter to complete an interception and destroy a bomber. The results given in Bomber Command O.R.S. Memo M.123 ('The Effect of Concentration in Time on Free-lance Cats-eye Fighters in the Target Area') (2), showed that it was advantageous to maintain a high concentration. Another investigation showed that if the duration of past raids had been reduced, losses would almost certainly have been lower, and that smaller raids would result in lower percentage losses than larger raids of the same concentration (Bomber Command O.R.S. Memo. M.124, 'Note on the Tactical Changes which would Reduce Losses in Night Operations') (3)

The direction of his fighters to the estimated target area was the immediate reaction of the enemy to the introduction of Window. After the creation of his running commentary and beacon system, he followed the bombers out from the target and this was followed by attempts to contact the bombers on the inwards journey also, leaving the fighters to free lance in the stream

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(1) A.H.B./IIH/258/1/14
(2)
(3) A.H.B./IIH/241/22/3.

to pick up bombers on their A.I. equipment. The danger resulting from this practice was carefully considered. Clearly, the more concentrated the bombers the more easily would the fighters obtain 'contacts' once they had found the stream. If, however, the bombers were less concentrated the stream would be longer or wider, and the fighters would find it more easily; but having found it, they would have greater difficulty in obtaining contacts. A balance would have to be found between these dangers.

Another important factor had also to be taken into account. If the concentration was reduced substantially the protection afforded by Window would be lost, and Bomber Command was well aware of the efficiency of the enemy G.C.I. system. While, therefore, the enemy's defences were gradually recovering from the devastating effects of Window, it was felt that it would be a retrograde step to dispense with this countermeasure as the enemy was now employing many more fighters to achieve about the same success as he obtained in the pre-Window period. Further, by increasing the concentration the density of Window was increased, making it more difficult for the A.I. operator to work within the stream. It was therefore decided that the policy of concentration should be continued.

While the air battle continued, much thought was being given by the Air Staff and the O.R.S. to the problem of tactics. The enemy's A.I. (Lichtenstein) was not particularly suitable for free lancing in the bomber stream due to its narrow beam. An improved form of A.I. was clearly to be expected in due course - there were already rumours of this equipment - and it was clear that if it proved suitable for free lancing, the Command's present tactics would have to be changed. The situation was carefully watched. By December, losses had risen again to 4.9per cent compared with 3.7 per cent in November, and a further rise to 5.9 per cent occurred during January 1944. While this rise was partly due to a series of heavy raids on Berlin, which generally involved higher losses than elsewhere, there was no doubt that the defence had completely recovered from the set-back due to Window and was steadily improving.

Two interesting proposals for confusing the enemy Controllers were put forward by No. 5 Group. They were:-

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(a) that the force should proceed on the outward journey in reverse order, i.e. with the Pathfinder Force in the rear, until sufficiently far past the target, when the whole force would reverse and attack.

(b) that the whole force should perform a side-step manoeuvre, i.e turn through 90° at a given time, fly in the new direction for a given time and return to the original course.

The O.R.S. was asked to examine these proposals. It reported as follows:-

'We have given careful consideration to the proposal put forward by No. 5 Group at Enclosure 83A (BC/S22870/Ops.1(e) for side-stepping the bomber force with a view to confusing the enemy defences. We think that this scheme should be useful in deceiving the enemy as to the target, and would be effective in reducing losses due to free lance fighters in the bomber stream. Straggling will undoubtedly be increased but this should not prove serious if the manoeuvre is restricted to an area in which the G.C.I. coverage is relatively thin. Further, the manoeuvre can only be carried out in selected areas, otherwise the bombers will fly over defended areas. We consider that the collision risk is very small. As regards the question of reversing the main force, we think that this is impracticable in view of the greatly increased collision risk and since, in view of straggling, timing at the target is likely to be upset. The method also involves an unnecessary increase in the length of time over enemy territory.'

A detailed report on the side-step proposal was given in Bomber Command O.R.S. Report No. B.194.(1)

The manoeuvre of side-stepping was tried out once, but was not satisfactory. The position with regard to losses clearly required much more drastic measures, and an investigation was called for. The O.R.S. accordingly made an examination of the tactical aspects of all major operations carried out in the period 22/23 November 1943 to 21/22 January 1944 inclusive, with a view to making detailed proposals for the future. The following recommendations were made in the report giving the results of the investigation subsequently published in Bomber Command O.R.S. Report No. B.197.(2)

(a) The following guiding principles should be observed in the planning of routes:- outward routes should be much more varied; they should not pass directly over the main visual night fighter beacons nor follow the natural path of flight between two beacons; no route should form a narrow loop round the target area, particularly if that loop encloses or is near to a fighter beacon; Benito-controlled fighters operating in coastal areas are temporarily less likely to be encountered if enemy territory is entered near the mouth of the Somme; for deep penetrations into Germany the southern approach appears to be temporarily less well defended and better adapted for combination with suitable diversion.

(b) The enemy's problem of putting his free lance fighters into the bomber stream is made easier by the length of the latter and therefore any reduction in the length of the bomber stream will be of value in reducing losses. This implies either the use of smaller forces attacking a number of targets or the planning of two or more widely separated routes to the same target.

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(1) A.H.B./IIM/a1/4a (31 Jan.1944).
(2) A.H.B./IIH/241/22/12.

(c) Since the enemy is aided in contacting the bomber stream by our route markers, it is recommended that their use be discontinued. The use of 'spoof' route markers, dropped by Mosquitos near to the enemy beacons likely to be in use, may, however, be worthwhile and is likely to be of more value than diversionary attacks by these aircraft.

(d) Although the use of multiple routes will lead to some dispersion of enemy effort, more attempts should be made to divert a proportion of the fighter force. Small diversionary attacks by Mosquitos are no longer of value and the attempts made so far to use heavy bombers for the purpose have been unsuccessful because the combined forces have proceeded too far along a common route, so that fighters have made contact before the stream divided. Diversions on a much larger scale, made by heavy bombers and with full complement of R.C.M. equipment are essential if success is to be achived. Pending the jamming of the enemy long range warning stations, a strong force of minelayers sent to the Frisians or a 'Bullseye' operation (1) routed well out across the North Sea might provide a suitable diversion for a main attack in southern Germany. Alternatively, for shorter range targets a second large attack, made possibly half an hour after a first main attack on the same target, might be expected to find the enemy fighters dispersed and to escape with small losses.

With the form of attack then used, practically the whole German fighter force drawn from long distances was employed against each raid. This was possible due to the depth of penetration and length of the bomber stream. The new proposals aimed at splitting up the fighter force and containing a part of it to defend a possible threat, and giving the enemy fighter control a more complicated problem. Also, by dividing up the bomber force between different routes and targets, the fighters would have greater difficulty in making contact.

After consideration by the Air Staff, the proposal was referred to the Commander-in-Chief who, on 25 February 1944, directed that the Command 'should from now on work as far as possible on these lines'. The Deputy Commander-in-Chief instructed that copies of the report should be sent immediately to the Air Officers Commanding of all operational groups for their personal information and comments, and a conference was called at Headquarters to discuss the whole subject of tactics. At this it was agreed that a committee, the Bomber Command Tactical Planning Committee, on which the O.R.S. was to be represented, should be set up forthwith to plan in outline the routes and tactics to be employed for certain main targets. This committee continued to function until the end of the war.

The replies received from groups were generally favourable to the recommendations made, and it was possible to inform them that agreement had

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(1) A training exercise by O.T.U. aircraft.

been reached on the necessity for large scale diversions, divided routeing on one target, attacks on two targets on the same night, split attacks in time and continual variations in tactics. In addition, it was decided that routeing over beacons, while undesirable, should not be allowed to interfere unduly with route planning, but that route markers should be dispensed with as far as possible. Further advice on the latter point was requested, and the results of a re-examination of the problem of the use of route markers was published in Bomber Command O.R.S. Report No. S.129.(1) The conclusions reached were:-

'That route markers have proved a source of danger by giving away the position of the bomber stream, and when accurate broadcast wind velocities are available the small additional benefits to be expected from improved track-keeping if route markers are used will not normally justify the acceptance of this danger. It is therefore recommended that route markers should only by used to concentrate the bomber force after a long sea crossing and provided that a satisfactory degree of concentration at this point cannot be achieved by normal navigational aids. When route markers are used for the above purpose, or if they are considered desirable in other circumstances, it is recommended that:-

(a) they should be dropped as far as possible, preferably not less than 30 miles from any fighter beacon that may be expected to be in use, and from the probable fighter routes

(b) they should be dropped at a distance of 20 miles off track on the side where the fighters are expected.

It is considered that the danger to crews will not be materially affected by the deviation from the track, particularly if backing up of the route markers is kept to a minimum. Since neither the use of off track route markers nor the use of Target indicators when wind broadcasting is in force have been assessed, it is proposed that navagator's logs shall be examined in this respect for the next occasion when off track route markers are used'.

The new tactics were put gradually into effect from the night 20/21 February 1944, with the result that losses were reduced immediately. This is shown by the following figures for percentage losses sustained in attacking targets in Germany.

Nov.1943	Dec.1943	Jan.1944	Feb.1944 1st 2 Ops	Feb.1944 last 3 Ops	Mar.1944 5 Ops	Mar.1944 2 Ops	Apr.1944
3.7	4.9	6.4	7.1	3.3	2.7	10.5	3.5

It is seen that, apart from two operations in March, the improvement obtained was substantial. The heavy losses suffered on the two nights in question (Berlin, 24/25 March; and Nuremberg, 30/31 March) cannot be

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(1) A.H.B./II H/241/22/14.

attributed in any way to the adoption of the new tactics. On the contrary, they provided further evidence in their favour since they were not followed on these nights.

Split attacks in time against the same target, involving the use of much smaller individual forces, were tried with considerable success on the last two nights in February; but in March, although much greater use was made of the southern approach to Germany and routeing was considerably more varied, few of the diversions planned were sufficiently large to affect the dispositions of the enemy fighter forces, and no attempt was made to reduce the length of stream by employing smaller forces. On both the 24/25 and 30/31 March, abnormal weather conditions were a contributory factor in causing high losses but, particularly on the 30/31 March when 96 heavy bombers were lost, the length of the bomber stream, following a single route, the nature of the ordered route and the absence of a proper diversion would almost certainly have led to high losses even under conditions less favourable to the individual fighters. The experience of this night proved conclusively the urgent necessity to adopt in their entirety the recommended principles of raid planning, and at the next meeting of the Bomber Command Tactical Planning Committee on 9 April 1944, it was stated that the Commander-in-Chief had agreed in principle to the attack of two targets on the same night and that divided routeing should be employed if suitable conditions prevailed.

As stated above, very high losses were sustained on the few nights when the new tactics were not used. These results encouraged the strong feeling that still persisted in certain quarters outside the Command that the concentration policy was unsound. Bomber Command considered, however, that the protagonists for de-concentration did not appreciate the great danger from the G.C.I. fighter which would have resulted had Window cover been discarded pending full introduction of electronic jamming (Carpet II). Before the introduction of Window about 60 G.C.I. fighters used to operate at any one time, whereas the number of free lance fighters used at the time under consideration was of the order of 300. With the same force of bombers, these 60 G.C.I. fighters shot down approximately the same number of aircraft

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which were now shot down by 300 free lance fighters (Internal Memorandum No. M.125, 'Suggested Methods of Reducing Losses to Free-Lance Fighters').(1) This paper reiterated that to avoid free lance fighters 'the stream should be as short and compact as possible. Adequate reduction in the length of a stream can only be obtained by employing small forces, and therefore more than one stream to the same or different targets should be employed wherever possible'. The general problem was constantly kept in mind, but on all occasions on which the position as regards concentration was reviewed by the O.R.S., the same conclusion was arrived at; namely, that all efforts should be directed towards preventing free lance fighters finding the stream, and that attempts to reduce the number of possible engagements by fighters which have found the stream should only be made if such measures do not increase their chance of finding it.

The policy of concentration was maintained, and from April 1944 onwards the size of the individual bomber forces was drastically reduced, the smaller forces in turn tending to become more and more compact. The planned concentration at bombing rarely achieved 30 aircraft per minute but, in practice, continued improvements in navigational methods gradually led to a much closer adherence to planned routes and bombing times, with the result that the actual concentrations achieved, both <u>en route</u> and at the targets, also gradually improved. After the ~~capture~~ Allied occupation of France, the Continental Gee chain was established, and this caused a great improvement in navigation with a marked reduction in the width of the bomber streams. From this time collisions became more frequent and the subject of concentration again came up for review. It was concluded, however, (Bomber Command O.R.S. Report No. S.206)(2) that the same arguments still applied and that maintenance of low losses to fighters was still the primary consideration. It was, however, proposed that the height spread of the whole force should be increased to 4,000 feet for short range targets, and that while within Gee range aircraft should be routed in two streams about eight miles apart.

The maximum success of the tactics adopted could only be obtained if the individual bomber forces were as compact as possible. Due to errors in

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(1) A.H.B./II/39/1/1
(2) A.H.B./IIH/241/22/14.

timing and navigation some aircraft were always to be found away from the main group, and were thus unprotected by Window and exposed to the enemy G.C.I. Apart from stressing the utmost importance of accurate track-keeping, consideration was given to the problem of making the smaller forces even more compact in length, while not dangerously increasing their concentration in space. This would have involved increase in the planned concentration in time with simultaneous planned spread in height. The main difficulties were the variation of wind with height and the different types of aircraft used in the Command. The conclusions reached in the report (No. B.212)[(1)] were as follows:- 'That the main danger to the bomber force, from free lance fighters, would best be combatted if all aircraft were to fly at very high concentration in a very narrow height band. This would have the additional advantage of giving predicted flak the least chance to operate effectively, but the collision risk would become intolerably high. To overcome this dilemma it was proposed that

(a) on nights when wind changes with height are likely to be great, the bomber stream should fly in a narrow height band about 2,000 feet, and the planned concentration at bombing should not be more than 40 aircraft per minute. In these circumstances, variations of height might be carried out at planned times and rates, thus imposing a further handicap on the free lance fighters.

(b) on nights when the wind changes with height can be confidently predicted to be small, say an overall change in wind vector of less than 15 m.p.h., the bomber stream should be dispersed uniformly in height over a band of about 5,000 feet and the planned concentration at bombing should be in the neighbourhood of 80 aircraft per minute. Steps should, however, be taken to ensure that those aircraft ordered to fly low do, in fact, do so'.

For how long the tactics adopted would have proved successful will never be known for as part of the preparations for Overlord arrangements were made to jam the enemy's early warning system by the Mandrel Screen (See Chapter 17) and from 'D' Day onwards Bomber Command's operations were supported by greatly increased radio countermeasures. The Mandrel Screen facilitated the operation of 'feint' tactics which were developed extensively by No. 100 Group, and the loss of early warning greatly handicapped the defence. As a result of the occupation of France and Belgium by the Army, penetrations ~~to German targets~~ over enemy occupied territory to targets in Germany became less and less, and from September 1944 the loss rate averaged less than 2 per cent. While, therefore, there were many

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(1) A.H.B./IIH/241/22/12.

anxious moments during the winter of 1943/44, the tactics and radio countermeasures support provided enabled Bomber Command to press home the offensive continuously and at maximum intensity consistent with its resources throughout the war.

Wave Plans

In the early days of Bomber Command's night operations, after large scale raids had begun but before the formation of the Pathfinder Force, it was found advantageous to begin each attack with a wave of bombers with specially experienced crews. The first wave of the attack was expected to find the target and to start conflagrations which should guide the less experienced crews at least to the neighbourhood of the target. In course of time, as the organisation of operations became more centralised, it was found convenient to develop a more complete system of division into waves for every large scale attack. The various waves of the attack were planned to follow one another, usually without any gaps between them, so that the effect produced was a roughly uniform stream of bombers over the target; the advantage of the division into waves was that each aircraft was briefed to arrive at the target at a definite period of the raid, thus facilitating the handling of the aircraft on their return and also making possible the specialisation of function of aircraft during the attack itself.

The system of attacking in waves, once instituted, was found to be capable of being used and modified for tactical purposes. The first step in this direction was made in the spring of 1943 when the concentration of aircraft over the target became habitually high. The higher-flying Lancasters were then usually placed in separate waves from the lower-flying Halifaxes, and the Halifaxes in separate waves from the low-flying Stirlings and Wellingtons. The O.R.S. concern with wave plans commenced with an attempt, in early July 1943, to determine the loss rates of bombers in the several waves of attack. The necessary data had to be specially obtained from groups for three operations, but no conclusive evidence could be deduced from it that losses were greater in one part of an attack than in another, since the division into waves amounted in practice to a division into types of aircraft.

/Wave

Wave plans assumed a much greater tactical importance with the introduction of Window in late July 1943. In order to make the best use of this countermeasure it was desirable amongst other things to keep the density of aircraft uniform throughout the length of the stream. The O.R.S. investigated the effect of the wave plans employed in the first few Window operations and reported (Report No. S.98) (1) that 'A consideration of the wave plans shows that the Stirlings are too early in the attack to obtain the maximum protection from the Window dropped by the higher-flying aircraft, and that the last wave of Halifaxes should be placed after the last wave of Lancasters in order to make use of the Window dropped by the higher-flying Lancasters. A revised wave plan is suggested - (the improvement being effected by arranging for those aircraft operating at the lower levels to be preceded immediately by the higher aircraft) - in which more use is made of the Window without any change in the risks to any particular wave. The Air Staff have agreed this suggestion but propose an additional wave of lower-flying Lancasters to cover the rear. Alternative wave plans are being investigated'. In attempting to devise new wave plans several complicating factors had to be taken into account. First, the fact that the original type of Window fell through still air at about 500 feet per minute made it desirable to arrange that each high-flying wave should be followed immediately by a wave of aircraft flying 2,000 - 3,000 feet lower, so that Window dropped by the earlier wave should be of benefit to the latter; thus, the waves should, for preference, attack in the order Lancaster - Halifax - Stirling. Second, the varying cruising speeds of the different types of aircraft made it certain that any wave plan designed to give maximum Window protection at the target would fail to give maximum protection on the outward and homeward routes; in particular, the Stirlings had to be put in the first half of the attack to avoid the danger of their straggling dangerously behind the other types on the homeward route. Third, the immediate reply of the German fighters to the introduction of Window was to concentrate their forces for free lance interception in the target area; in order to make the task of these fighters harder it was desirable that the height of attack of the successive waves should vary widely and

/irregularly

(1) A.H.B./ID/12/113.

irregularly, so that the fighters should have less chance of either finding or being directed to the height level at which the bombers at any moment were concentrated. Fourth, this same fact of concentration of fighters over the target made it essential to shorten the duration of raids by some means which would ensure the least probability of high peaks in the concentration of aircraft bombing at any minute, and therefore the least probability of increasing the risk of collisions and damage by falling incendiary bombs.

Within these limitations several alternative wave plans were worked out by the O.R.S. (Memorandum No. M.126, 'Wave Plans on Window using Raids')[1] the fundamental principles of which were taken into account by Air Staff in planning the wave plans used during the autumn and winter of 1943. These were necessarily a compromise to meet the very conflicting requirements of the situation and, while a certain amount of variety was used to add to the difficulties of the fighters, the basic principles of keeping each wave to a moderately narrow height band was conserved. The main proposal was that by using Halifaxes in the first or first two waves, followed by the Lancasters, a more uniform concentration at the target would be achieved, the stream would become more compact on leaving the target area and the lower-flying and slower aircraft would be away from the target area before the fighters arrived. At this time little danger was anticipated on the outward route and fighter opposition usually commenced at the target. However, during December 1943 conditions radically changed and the enemy changed over to the policy of route interception. This made the proposed plan, which had already been used, potentially dangerous, as was pointed out in a further note, Memorandum No. M.28 [2] dated 4 January 1944.

Shortly after this time first the Stirling and then the Halifax II and V aircraft were withdrawn from the main operations, and the aircraft of the Command became roughly of equal performance so far as operational heights and speeds were concerned. At the same time the enemy continued to use

/route

(1) A.H.B./IIH/241/22/3.
(2)

route interceptions and for these two reasons the system of wave plans lost most of its tactical importance as a defensive measure. It was, however, retained to the end of hostilities as a convenient means of regulating the flow of bombers over the target .

Effect of Moonlight on Bomber Losses

The effect of moonlight on bomber losses was originally studied in connection with the early investigations into the desirability of concentrating the bomber force in space and time. For the targets then investigated it was found that while on dark nights losses decreased markedly with increasing concentration of the force, the evidence for concentration was not quite so strong on moonlights and it was presumed that the operation of free lance cats-eye fighters was assisted by a concentrated bomber stream on moonlight nights.

These earlier investigations had to be made with rather scanty data, which did not permit much sub-division according to the different operational conditions. In due course, however, an analysis was made of sorties, losses and fighter interceptions for all night operations in the period 1 August 1941 to 31st October 1942. This period was sufficiently long to provide a considerable amount of data, capable of sub-division into types of operation and main target areas, each of the latter being in turn subdivided according to cloud conditions prevailing during operations, the state of the moon and the types of aircraft concerned. The results, which were published in Bomber Command O.R.S. Report No. 66.(1) dated 13 January 1942, showed that during the period under review the losses sustained in most target areas were heavier in operations in which the moon was up during the time over target, but this was not true of the Ruhr and Lower Rhine area where heavier casualties were suffered on dark nights. ~~Against the three main Ruhr targets, casualties were suffered on dark nights~~. Against the three main Ruhr targets, namely Essen, Dortmund and Duisburg, losses have been roughly 50 per cent greater in operations carried out in the dark than in those carried out in moonlight.

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(1) A.H.B./II/39/1

At this time the attacks made on Ruhr targets were achieving very little in the way of results owing to the difficulty of identifying these targets, particularly in the dark. The conclusions reached in the above report were based on the analysis of a large number of sorties, and there was little doubt about their correctness. In the circumstances, it was thought that the evidence was sufficient to justify making the experiment of attacking Ruhr targets on moonlight nights only, when the chances of correct target identification would be much better. A further argument in favour of this policy was that at this time the deeper penetrations into enemy territory were usually made in moonlight and these frequently resulted in high losses to free lance cats-eye fighters. The Air Staff, however, did not try out the experiments and the majority of attacks on Ruhr targets continued to be made in the dark.

A further analysis of the effect of the moon on loss rate, made in May 1943, confirmed the impression that the adoption of the policy of attacking Ruhr targets on moonlight nights only might well have been worthwhile. Its conclusions were:- 'Many influences bear on the missing rate and it would be rash to conclude that the (general) trends shown are entirely due to the phase of the moon. It can, however, be said with confidence that in the past year the Ruhr area is the only one in which there has been no evidence of a higher overall missing rate or of a tendency for high missing rates for single operation to occur during the moon period. In all other areas there is some evidence of such a tendency.' A later note on the losses incurred by Bomber Command in attacks carried out by moonlight, is given in Memorandum No. M.130.(1)

Tactics on Very Light Nights

The night bomber offensive was started because of the high losses sustained on daylight operations, and it was decided that our bombers should not be flown over or near enemy territory except during the hours of darkness, and these were determined from the Nautical Almanac, it being assumed that it was sufficiently dark to fly over enemy territory at nautical twilight, i.e. when the sun was 12° below the horizon. Certain corrections

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(1) A.H.B.IIH/241/22/3.

for height - to obtain any given degree of darkness - were given in the Nautical Almanac and these were used. However, analysis showed that both the loss rates and the percentage of sorties intercepted by fighters rose in the summer months, and there were many reports from crews which spoke of the lightness in the northern sky during the summer period. The views of the O.R.S. were requested by the Navigation staff and they recommended that it was essential to carry out some experiments to determine the brightness of the sky at various heights during the summer months. It is not possible to give a full technical discussion of the work done and here it will merely be mentioned that the method used for calculating the time of onset of darkness given in the Nautical Almanac was found to be erroneous and a correct means of forecasting the time of darkness was found. The tactical implications of the lightness of the sky were considered and are discussed in detail in Report No. B.214 'The Effect of Twilight on Bomber Operations'[1] and in a paper 'Bomber Tactics during Very Light Nights', Report No. B.211.[2] ~~B.237.~~[2] It was found that the silhouette visibility of aircraft at twilight in the direction of the sun is greatly increased, while visibility in the opposite direction is not much greater than on normal nights. Hence, although fighters - who chose the direction of attack in which the visibility was greatest - would always have the maximum advantage, the bomber would only have a slightly greater than normal visibility range on a fighter. It followed that in order to keep Bomber Command losses down to a reasonable low level on midsummer nights, the bomber force should:-

(a) fly low

(b) keep as far south as possible

(c) attack targets of minimum penetration.

The Report No. B.214 was agreed in principle by the Air Staff who, however, would not agree to its circulation outside the Command on the grounds that the information on the visibility ranges of bombers on summer nights was likely to have a harmful effect on the morale of aircrews. The paper on bomber tactics during very light nights was considered by the Commander-in-Chief and discussed at a meeting of the Bomber Command Tactical Planning

/Committee

(1) A.H.B./IIH/241/22/12.
(2) A.H.B./IIH/241/22/12.

Committee held on 24 June 1944. The paper suggested that for an attack on the Ruhr by about 300 aircraft, there seemed to be two ways of minimising the number of fighter interceptions, namely either by:-

(a) an attack by six successive two-minute waves of 50 aircraft each proceeding and leaving the target by different routes. The route being spread over a front of about 70 miles

(b) an attack by six waves of 50 aircraft each proceeding and leaving the target by different routes but all waves attacking simultaneously over a period of 12 minutes.

Both these proposals were accepted by the Commander-in-Chief.

Policy of Opening Fire First

In Bomber Command O.R.S. Report No. 49 (1) the June number of the 'Monthly Report on Losses and Interceptions of Bomber Command Aircraft in Night Operations', it was pointed out that only a small proportion of approaching enemy fighters persisted in their attack when the bomber opened fire on them first. In the July number, Bomber Command O.R.S. Report No. 51 (2) it was stated that 'it would appear that while the bomber may reveal its position by taking the initiative in this way, aggressive tactics are successful in many cases in preventing attack', and in the September number, Bomber Command O.R.S. Report No. 59 (3) states 'there were undoubtedly several encounters in which intended attack from astern or the quarters was forestalled by opening fire from longish range'.

On 21 June 1943, the Air Officer Commanding No.5 Group instructed gunners of his group to open fire at once on all identified enemy fighters and in August 1943 a Tactical Note on 'Bomber Self Defence at Night', issued by Bomber Command, recommended that all groups should do the same.

Although this formed the basis of policy for all groups, greater emphasis appears to have been placed in No. 5 Group on the desirability of opening fire at the earliest possible moment. After the increase in concentration of aircraft in the bomber forces, which became necessary owing to the changed enemy fighter tactics resulting from the use of Window, reported cases of attack by four-engined bombers became more frequent and, particularly in the case of No. 5 Group, a very noticeable increase occurred in the number of combats with enemy night fighters.

/Doubts

(1) A.H.B./IIK/54/6/5.
(2) A.H.B./II/39/1.
(3) A.H.B./IIK/54/6/5.

Doubts arose as to the wisdom of the super-aggressiveness shown by the No. 5 Group gunners and, after conversations with Headquarters, the Air Officer Commanding No. 5 Group suggested that the O.R.S. should examine the results achieved since the introduction of the policy of opening fire on all identified enemy aircraft, and in particular compare No. 5 Group's records with those of the other operational groups.

The comparison was made mainly on the basis of the Lancasters of Nos. 1 and 5 Groups operating in the same phase of attacks for two four-monthly periods immediately preceding and succeeding the date on which No. 5 Group started its greater aggressiveness to fighters. It was concluded (Report No. S.113) [1] that too great a readiness to open fire, as in the case of No. 5 Group, had resulted in an increased risk of attack by fighters and that a small, but growing proportion of bomber sorties were being attacked and damaged by fire from other bombers. While some of these incidents were due to premature firing on unidentified aircraft, the majority resulted from mistaken identification. It was considered that the results warranted a warning to crews not to fire on unidentified aircraft and a recommendation that the strongest possible effort should be made to provide means for identifying friend from foe.

The Use of Tracer Ammunition

The merits of the use of tracer ammunition for the guns of bomber aircraft were debated throughout the course of the war, and the O.R.S. was asked by the Training Armament Branch to consider the question at the end of 1944. A short paper (Memorandum No. M.128, 'Pros and Cons of Tracer Ammunition for Bomber Aircraft) [2] was therefore prepared in which it was pointed out that, owing to its poor ballistics, tracer was useless for the purpose for which it was originally made, namely to assist in aiming. Its advantages and disadvantages are discussed in the paper which recommended that the problem of producing tracer ammunition which does not distract the gunner from his sight should be re-examined.

/Evasive

(1) (2) A.H.B./IIH/241/22/14.

Evasive Action from Heavy Flak

The O.R.S. interest in problems connected with the evasive action taken by bombers from heavy flak commenced immediately after its formation in September 1941. Its representative attended a meeting held at Headquarters Bomber Command on 30 October 1941, to discuss the subject with Professor Mott of the Ordnance Board, and as a result compiled a note summarising the recommended procedures to be adopted for evading flak and searchlights under given conditions. In January 1942 Report No. 27 'Statement on Aircraft Casualties to Flak according to Target Attacked' (1) prepared for the Tactical Sub-Committee on A.A. Fire of the Operational Research Centre, gave an account of the evasive tactics employed by Bomber Command aircraft on night operations from information supplied by the Operations Branch of the Command. At this time no standard evasive tactics were laid down and those employed in practice varied with the individual pilots, and according to the various conditions encountered, usually consisting of alternating changes in course, with simultaneous changes in height, of varying degrees of intensity.

In October 1942, O.R.S. representatives attended trials carried out under the direction of the Army Operational Research Group to determine whether 'violent evasive action' (height variations up to 1,000 feet accompanied by changes in course) would prevent any attempt at engagement by 'seen' fire. It was found that it did not and that under these circumstances the 'seen' fire would have been about as effective as contemporary 'unseen' fire against a target taking no avoiding action. About the same time, a method for determining the evasive action taken by pilots in target areas, from a study of light tracks on the night photographs taken with bombing, was developed by the Central Interpretation Unit, and the O.R.S. commenced an analysis of the results obtained by this method. The knowledge resulting from these investigations was thus available when the Commander-in-Chief requested that the O.R.S. should examine the whole problem of evasive action from flak in target areas. The request arose from the doubts as to the value of the evasive action normally taken and the concern felt at the current poor standard of bomb aiming.

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The importance of the conclusions drawn from the O.R.S. investigation was sufficient to justify immediate action while awaiting publication of a report, and on 5 May 1943 the Commander-in-Chief issued instructions to all operational Groups as follows. The O.R.S. of this Headquarters is of the opinion that over a hotly defended target evasive action for the avoidance of flak is meaningless, especially when a high concentration of aircraft is achieved. The collision risk is seriously increased. It results in no saving of aircraft. Attempts by turning away to avoid flak bursting ahead are just as likely to lead to a hit from other bursts off the original track. Violent evasive action makes it impossible for gunners either to see or hit attacking fighters. Heavy bombers cannot "out manoeuvre" properly handled fighters. Finally, evasive action in the target area makes accurate bombing impossible and therefore necessitates repeat attacks; these in turn lead to a higher overall total of casualties in achieving a given object.

On the night of 4/5 May, No. 5 Group issued an order that during the attack on Dortmund no evasive action was to be taken during the run-up to the target. Everything was to be subordinated to accurate bombing, no matter what the apparent risk. The aircraft were to fly as high as possible. The result of this bears out in the most striking manner the contention of the O.R.S. that over a heavily defended target evasive action is just as likely to achieve a hit from flak as to avoid one. Of 125 Lancasters of No. 5 Group employed on this target in this manner only one was missing. All Air Officers Commanding should consider this example, which may in fact prove to be misleading, and carry out similar experiments themselves so that sure data can be acquired towards a definite conclusion. I need hardly point out that the vastly improved bombing which would result if, in fact, we find that evasive action does not pay and that a direct run across the target exposes the aircraft to less risk than the longer run caused by weaving and violent evasive action'.

The O.R.S. report was published very shortly afterwards in the form of a Bomber Command Tactical Memorandum, from which the arguments put forward for the abolition of evasive action in target areas, except when held in searchlights, were to be communicated to aircrew members. In June,

/instructions

instructions were sent to the O.T.Us that the same principles were to be embodied in aircrew training and that the teaching of any precautionary evasive action was to cease.

In the report an examination was made of all types of enemy A.A. fire and of the expected effect of each against a concentration of aircraft. Current examples of the evasive action taken in target areas, as determined from the night photographs taken with bombing, were also examined. It should here be mentioned that the information gained on the amount of evasive action undertaken by Bomber crews over the target was of great value to T.R.E. in their design of a stabilised H2S scanner.

Collisions and Falling Bombs

The chance that aircraft of Bomber Command should damage one another while over enemy territory on operations, either by colliding or by air-to-air bombing or by the turbulence of their slipstreams, was negligible before the spring of 1942. In O.R.S. Report No. 29 [(1)] dated 7 February 1942, definite recommendations were made that the concentration of attack in night operations should be increased, but the danger likely to arise from collisions and falling bombs was not considered to be a factor worthy of mention. This disregard of the collision and falling bomb risk was justified by events, since, in spite of concentrations several times as great as those obtaining previously, only one recorded case of damage from a falling bomb and no recorded case of damage or loss by collision had occurred up to May 1942.

On 26 May 1942, the Commander-in-Chief of Bomber Command asked the O.R.S. for an estimate of the frequency of collisions and of damage by air-to-air bombing [(2)] during an attack in which the concentration of aircraft in time would be of the order of 1,000 per hour. This request was prompted by the then imminent 'Thousand Plan' raid on Cologne, and an immediate answer was required. The answer, given within a few days, stated that the frequency of collisions would be not more than one per hour, and the frequency of air-to-air bomb strikes about five per hour. These two figures

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(1) A.H.B./II/70/369.
(2) The main risk was from 4lb incendiary bombs which made up the main bomb load.

were arrived at by two different methods, which were the foundation of all subsequent work on the problem. The first method, which was used to derive the figure for collisions, was to argue from the fact that a known number of raids had been carried out in the past without (as far as was known) any loss or damage by collision, and the fact that the frequency of occurrence of collisions increases only as the square of the concentration of the bombers in time. From these two facts a rough upper limit was found for the collision risk under the proposed conditions of extremely high concentration, although there was not time to marshal the evidence with any attempt at completeness. The second method, which was used to derive the figure for falling bomb damage, was to make a direct calculation of the chance of an aircraft being hit by a bomb, assuming a simple mathematical distribution of aircraft in space and time over the target. There was not time to make allowance in the calculation for several factors of practical importance, such as the degree of separation of the bombs falling from a single aircraft, but nevertheless, the formula arrived at was not greatly different from the more elaborate ones used later.

Clearly, both of the methods can, in theory, be used to estimate both collision and falling bomb risks. A direct calculation of the collision risk by the second method was begun in May 1942, but the problem was found to be considerably less tractable than the direct calculation of falling-bomb risks, and no numerical results were obtained. Meanwhile, the experience of the first 'Thousand Plan' raid on Cologne on 30/31 May confirmed the prediction of the O.R.S. that the losses to collisions and air-to-air bombing would be a small fraction of the total losses. In fact, only one collision was observed and the losses sustained on the operation below average. Since at that time it wasnot envisaged that even higher concentrations might be adopted in the future, the Command was satisfied with the knowledge that under 'Thousand Plan' raid conditions the losses to those causes would be small, and work on these problems by the O.R.S. was suspended for nearly a year.

In March 1943 the introduction of Oboe Ground-marking caused a sudden increase in the average concentration of aircraft in space in the target area. Hence, although concentration in time was not increased much above

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the 'Thousand Plan' level, there began in the spring of 1943 a succession of cases of air-to-air bombing and collisions over enemy territory which became steadily more frequent as time went on. This caused a request from the Deputy Commander-in-Chief that the O.R.S. should re-examine these questions in greater detail. As a result there was published in June 1943 ~~the~~ O.R.S. Report No. B.140,[1] in which the falling-bomb problem was for ~~the~~ the first time made the subject of a thorough and scientific analysis. The methods used in the study rested upon the comparison of figures from three sources, first the numbers of aircraft of various types which returned damaged by bombs, second the total number of aircraft which would theoretically be expected to be hit by bombs, and third the proportion of bomb-strikes on aircraft ~~which would be hit by bombs, and third the proportion of bomb-strikes on aircraft~~ which would be expected from structural considerations to cause lethal damage to some vulnerable area. These three sets of figures were found to be in fairly good agreement, and led to the conclusion that falling bombs were quite capable of causing the loss of aircraft, but would not destroy more than 0.1 per cent of sorties even in large-scale and highly concentrated attacks.

The practical effect of this work was mainly to relieve the anxiety of the Command concerning the possible magnitude of the falling bomb danger. With the purpose of allaying the fear of this danger, which was naturally widespread among aircrew, it was decided that Report No. B.140 should be circulated to Air Officers Commanding of groups who would then be able to disseminate the conclusions of the report more widely throughout the Command. The report thus removed one of the main objections to the policy of increasing still further the concentration of the bomber stream in time, which was put into effect in the autumn of 1943. A secondary practical effect of the report was to strengthen the case for the introduction of incendiary clusters to replace the small bomb containers in use at that time; the report confirmed, what was known already, that practically the whole of the falling-bomb risk would be eliminated if the use of the small bomb containers were discontinued. However, it cannot be said that this knowledge

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(1) A.H.B./IIH/241/22/12.

was of much practical benefit to the Command, since production and storage difficulties held up the introduction of incendiary clusters until 1944, and small bomb containers were still being used until the end of the war.

During the summer of 1943 the O.R.S. was collecting information with a view to producing a report which should elucidate the collision problems in the same way as Report No. B.140 had disposed of the falling bomb problem. However, for the reasons given below such a report was never issued.

As in the falling bomb problem, the chief aim of the O.R.S. in analysing the collision problem was to determine the actual number of bombers destroyed by collisions over enemy territory in a given period. Observations of lethal collisions by the crews of other aircraft could not be regarded as either reliable or complete enough to give much assistance in determining the frequency of such collisions. The evidence upon which the determination had to be based was therefore, as in the case of falling bombs, necessarily indirect and in practice confined to the following three sources: first, the statistics of bombers which had returned to England damaged in collisions second, the total frequency of collisions in the bomber stream as calculated by theoretical methods; and, third, the estimated chance of survival of a bomber involved in a collision. The principal reason why the collision problem proved so intractable was the lack of precision of the second and third of these sources of evidence. The theoretical formula for the number of collisions to be expected in a bomber stream depended to a critical extent on the small deviations of the bombers from their prescribed course, and the magnitude of these deviations could only be guessed at. Similarly, it was impossible to obtain from structural considerations any reliable upper limit to the probability of loss of an aircraft involved in a collision, as had been possible in the estimation of air-to-air bombing losses. The best estimate that could be obtained for this probability of loss was derived from the statistics of aircraft damaged and destroyed in collisions over England; this estimate was unreliable, first because the figures upon which it was based were small, and secondly because the conditions under which collisions usually occurred over England were totally different from the conditions obtaining in a bomber stream on operations.

Because of these difficulties, the draft report on collisions which was produced by the O.R.S. in December 1943, covering the period from May 1942 to September 1943, was lengthy and diffuse and lacking in definite conclusions. It stated that the evidence pointed to a figure of 0.2 per cent of sorties as the true order of magnitude of losses to collisions under the conditions obtaining at the end of 1943, but this conclusion was reached with so many reservations that it was not considered advisable to publish the draft as an O.R.S. report. However, the results of the investigation were communicated to the Air Staff, and played a fundamental part in determining their decision to maintain the concentration of the bomber stream at a very high level during the ensuing months, on the grounds that losses to collisions would remain of little importance compared with losses to enemy action. Moreover, in the course of the collection of data for the main report, various subsidiary questions concerning collisions were answered, and the answers communicated informally to those interested. In particular, four such questions form the subject of four Internal Memoranda. In the first Memorandum, No. M.80, 'The Effect of a Diving Turn on Collision Risk',(1) dated 13 August 1943, it is shown that the execution of a diving turn by a bomber upon receipt of a Monica warning, will not in general greatly increase the collision risk. In the second, No. M.82, 'Variations in Concentration and their Effect on Collision Risk',(2) dated 23 September 1943, the consequences of a particular method of regulating the heights of bombers are analysed. In the third, No. M.85, 'Notes on the Effect of Time-wasting on Collisions' (3) dated 21 December 1943, recommendations are made for the least dangerous methods by which bombers in a concentrated stream should alter their course in order to avoid arriving at the target too early. In the fourth, No. M.83, 'Note on the Collision Risk in the Execution of a Simultaneous Turn by a Concentration of Bombers' (4) dated 18 January 1944, an answer is given to a question proposed by the Air Staff as to whether an excessive collision risk would result from this manoeuvre. Each of these four memoranda gave results which were of some assistance to the Air Staff in the tactical direction of operations.

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(1) A.H.B./IIH/241/22/3.
(2) A.H.B./IIH/241/22/3.
(3) A.H.B./IIH/241/22/3.
(4) A.H.B./IIH/241/22/3.

In the spring of 1944, in response to a request for information from the Secretary of State for Air and the Command Air Staff, a second effort was made by the O.R.S. to provide material for an authoritative report on the collision problem. A Memorandum No. M.89,(1) in which the data and methods of analysis were similar to those of the earlier investigation, was produced in April 1944, covering the period from October 1943 to March 1944. This paper suffered from the same defects as the earlier one, and was not published generally for the same reasons. However, as before, the main conclusions of the investigation were made known to the Air Staff, and these confirmed the opinion stated in the earlier draft that the losses to collisions were not so high as to make advisable a reduction in the concentration of the bomber stream.

In January and February 1944, the O.R.S. was asked to give estimates for the magnitude of the expected losses to collisions in two new types of operation which were at that time being planned as part of the preparations for the invasion of Europe. These two types of projected operation were, first, a precision bombing attack in darkness on a small lightly-defended tactical target by a moderate force of heavy bombers, and second, a flight into enemy territory of a large mixed force of glider-towing and parachute-troop carrying aircraft in a concentrated stream by night. The estimate for the precision bombing operation was requested by the Air Staff at Bomber Command, and that for the glider operation by O.R.S. Allied Expeditionary Air Force. In each case the collision risk could be calculated without difficulty from theoretical considerations, given the dimensions and movements of the forces involved, although it was questionable whether the given dimensions could be adhered to in practice. The results were communicated to the enquirers in Memorandum No. M.86,(2) 'The Collision Risk involved in a Precision Attack on a Single Mark by a Moderate Number of Heavy Night Bombers', and in two letters addressed to O.R.S., A.E.A.F. The general conclusions reached were that in the case of the bombing operation collisions would not be a serious danger, while in the case of the glider operation the risk might be very severe. These results found their application during the

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(1) A.H.B./IIH/241/22/3.
(2) A.H.B./IIH/241/22/3.

ensuing months, when the tactical bombing campaign on French targets opened in March 1944 with many successful operations carried out with negligible losses, ~~all naviga-~~ and the airborne invasion of the night of 5/6 June was carried out with all navigation ~~tion~~ lights switched on so as to avoid collisions.

The theoretical methods used to calculate the expected number of collisions between aircraft under various conditions, for example the conditions of the two investigations just mentioned, are explained in a mathematical paper, Memorandum No. M.81,(1) entitled 'Note on the Theoretical Evaluation of Collision Risks'. This paper contains a rigorous deduction from risk principles of the various forumlae used in practice to calculate collision risks, and shows precisely what are the assumptions which have to be fulfilled in order that the formulae should be valid.

After April 1944, work on the collisions and falling-bomb problems was suspended for some time, although the O.R.S. continued from time to time to answer questions on these topics from various branches of the Command and Air Ministry. Meanwhile, with the liberation of France and Belgium, conditions were at last becoming more favourable for a fundamental attack on the collision problem. During the autumn and winter of 1944/45, large streams of bombers were frequently flying over allied occupied territory, under conditions not greatly different from those habitually obtaining over enemy territory. There thus gradually grew up a considerable number of recorded collisions occurring under such conditions; and in almost every case it was possible to determine with reasonable certainty whether the collision, if it had occurred over enemy territory, would have caused the loss of one or both aircraft involved. Hence, it became possible for the first time to obtain a reliable figure for the lethality of collisions, that is to say, for the proportions of aircraft involved in collisions over enemy territory which become missing. This proportion was found to be approximately 65 per cent.

Knowing approximately the lethality of collisions, and having the current records of aircraft returning damaged after being involved in collisions, it was possible in February 1945 to write a draft report which /gave

(1) A.H.B./IIH/241/22/3.

gave much more detailed and accurate information concerning the magnitude of the collision risk than had been contained in the earlier memoranda. This Memorandum No. M.87 [1] was written at the request of the Air Staff as part of a general examination by O.R.S. of the Command's policy of concentration, and its conclusions were embodied in Report No. S.206,[2] which was published on 6 March 1945, and assessed the advantages and disadvantage of that policy from various points of view. Memorandum M.87 covered the period from April 1944 to January 1945, and its main conclusion was that the losses due to collisions, although increasing towards the end of that period, had at no time greatly exceeded the figure of 0.25 per cent of sorties. This conclusion was published in Report No. S.206, with the recommendation that concentrations should not be reduced in order to diminish the collision risk, because the night fighter remained by far the most dangerous cause of loss of bombers. This recommendation was accepted by the Command, and remained the basis of the Command's tactical policy until the end of hostilities. The frequency of collisions, which had alarmed the Air Staff by mounting dangerously high during January 1945, remained steady during the final months of the war.

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(1) A.H.B./IIH/241/22/3.
(2) A.H.B./IIH/241/22/14.

CHAPTER 16

MISCELLANEOUS INVESTIGATIONS CONCERNING BOMBER LOSSES

The Causes of Bomber Losses

In the previous chapter the various investigations which the O.R.S. made into the tactics employed by the Bomber Force with a view to keeping losses to a minimum were described. The O.R.S's investigations into the application of radio countermeasures and other protective devices used by the bombers will be discussed in Chapter 17. In order that development might proceed on the most profitable lines it was necessary to determine the causes of bomber losses, and at frequent intervals throughout the war the O.R.S. was asked to provide estimates of the relative proportions of losses to fighters, flak etc. The subject was an extremely difficult one. The proportions in fact varied from time to time and from target to target, but sufficiently accurate figures were obtained to enable the policy on radio countermeasures etc to be formulated.

The estimates of the proportions of aircraft lost to different causes were based on a number of sources of information, such as:-

(a) the observations of returning bombers

(b) the percentage of bombers attacked

(c) the percentage of bombers hit by flak

(d) interrogation of 'escapers' and 'evaders'.

The first attempt to assess the causes of bomber losses was based on a study of the observations made by returning aircrew. The method was used continually throughout the war to keep a watch on the situation, and also provided information on the positions at which losses occurred, which was of value in investigating tactics. There is no doubt that a high proportion of losses sustained were observed by other bombers, due largely to the high tendency for bombers to catch fire when successfully engaged by the enemy. The reports had, however, to be carefully cross-checked for time and position to avoid duplication and reporting of other incidents such as 'scarecrow' flares.

Taking all targets and all weather conditions, both of which influenced the loss rate, the O.R.S. reached the view in May 1942 that our losses which represented about 4 per cent of sorties despatched were distributed as follows:-

25% + to enemy fighter

25% + to flak

20% to causes other than enemy action.

Further study of the problem enabled the O.R.S. to state in November 1942 that non-enemy action losses were about 10 per cent of total losses, while the remaining 90 per cent appeared to be equally divided between fighter and flak.

In early 1943 an overall review of the losses sustained during 1942 was made in an endeavour to reach a firmer assessment of the proportion of the Command's losses due to various causes. The results were given in Bomber Command O.R.S. Report No. S91 [(1)] and considered only attacks on German targets. It must be remembered thatlosses varied with target attacked, type of aircraft, weather conditions and experience of the crew. Further, throughout the year there was a clear tendency for losses to rise, the rise being greater in some areas than others. As a result of all the information available at the time, the O.R.S. assessed bomber losses towards the end of the period to be as follows:-

to fighter	2½%	i.e.	55%
to flak	1½%	i.e.	30%
non-enemy action	½%	i.e.	15%
	4½%		100%

It should be mentioned, however, that whereas losses to fighter rose from about 1 per cent to 2½ per cent during the year, those due to flak were thought to remain at about 1½ per cent. This demonstrates the danger in ascribing a certain proportion of losses to one cause. Except under special circumstances such as low flying attacks and very bad weahter, which on a few occasions resulted in losses well above average, the O.R.S. was confident that the variation in the loss rate was largely due to the varying success achieved by the fighters, the losses due to flak remaining at about 1 to 1½ per cent.

In mid-1943, a series of orders of the day of Fliegerkorps XII for the period December 1942 to May 1943 was captured in Sicily, and A.D.I. (Science) produced a report (Air Scientific Intelligence Report No. 21) [(2)] analysing the details. They assessed the proportion of our losses due to fighters over

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(1) A.H.B./IIH/241/22/14.
(2) A.H.B./II/77/21.

the period as being 64 per cent. On a 4½ per cent loss rate this would credit about 3 per cent to the fighters.

One of the methods used for determining the loss rate due to different causes was discussed in Bomber Command O.R.S. Memorandum No. M.138.[1] In this method the correlation coefficient between the numbers of aircraft missing, numbers returning damaged by flak, and numbers having had combats with fighters was determined, and the regression equation connecting the three variables found. It was concluded that about three times as many aircraft were lost due to fighters as due to flak. This result suggested that the losses attributed to fighters in Bomber Command O.R.S. Report No. S.91 were[2] probably a little low, which agreed with the conclusions reached from the captured documents.

The relatively high proportion of losses allocated by the O.R.S. to flak was challenged by some of the A.A. authorities in this country, and a number of studies were made, particularly by the Army Operational Research Group to determine the relation between the number of strikes on returning bombers and the probable losses. These studies and the success of ~~our own~~ Allied A.A. all indicated that our losses due to flak should have been lower. The general view expressed in Memorandum No. M.143 [3] denied the certainty of the conclusions reached on the grounds that no allowance was made for the cumulative effects of several strikes not on the so-called vulnerable areas and the seriousness of the fire risk. While the difference was not large, at the most ½ per cent, it is probable that the O.R.S. assessment of losses to flak was on the high side. This minor discrepancy was, however, unimportant, since the correct decisions, namely to counter the enemy fighters, had been taken on the information available and a general appreciation of the position.

As time went on, two further sources of information became available to the O.R.S. namely, messages from Prisoner of War Camps as to the way in which aircraft containing the personnel in the camps had been brought down, and the experience of aircrew shot down who succeeded in returning to this country. The results of an examination of the former are given in Memorandum No. M.137.[4] Very valuable information was obtained from the latter source, and,

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(1)
(2) A.H.B./IIH/241/22/14.
(3)
(4) A.H.B./IIH/241/22/3.

as described below, the interrogation of such personnel became an O.R.S. responsibility.

Information from Returned Aircrew Survivors

When returned aircrew arrived in this country they were interrogated by the Air Intelligence branch, who issued a report. These reports were very interesting to the O.R.S., and when in May 1943 the Assistant Director of Intelligence (K) found it impossible to continue the interrogation, the O.R.S. decided that it was undesirable for the information to be lost and accordingly arranged to undertake the interrogations.

The method of contacting evaders and escapers was at a Personnel Reception Centre (P.R.C.) immediately on their return. They were asked to tell the full story of the flight up to reaching the ground after the final incident, and as much detail as possible was elucidated by careful questioning. The interrogators were briefed beforehand with a list of the types of information likely to be important, and were already experienced in the general tendencies of the loss of aircraft as well as being expert in some particular subject. The story was written up in narrative form and published with a limited circulation. (These reports were known as Bomber Command O.R.S. 'K' Reports of which 282 were issued).(1) The evader was also interrogated by Military Intelligence 9 concerning his adventures on the ground, and a separate report published.

After the liberation of France, a number of damaged aircraft managed to return behind the Allied lines before being abandoned. In the previous period these aircraft would have been 'missing' and any evaders would have been interrogated. As information regarding their experiences was of value, it was eventually arranged in December 1944 that these people should be interrogated at groups by the Intelligence personnel, and the reports sent on to the O.R.S.

With the ending of the German war and the extremely rapid return of repatriated P.O.Ws, it had to be considered whether these men ought to and could be interrogated. It was decided that not to do this would entail a loss of information, potentially valuable, concerning subjects such as fires

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(1) A.H.B./IIH/241/22/2.

in aircraft, and aircrew safety arrangements etc; much of this information having a probable bearing on future aircraft development. It was desirable that this interrogation should take place before the ex-P.O.W. went on leave as their stories were likely to be more factual than after continual repetition and possibly understandable exaggeration in the home circle. The organisation at the Personnel Reception Centres with a maximum duration of stay per man of 48 hours, had already been set up without our knowledge and we were therefore constrained to fit our interrogation into the existing scheme without any increase of time. The whole question had to be dealt with in great haste as the time that elapsed between our first hearing of the P.R.Cs and their opening was only just over a fortnight. During this period an organisation has to be devised, a questionnaire drawn up and printed and this had to be fitted to the system in use at the P.R.Cs when this was learnt. Consequently, it was not possible to consult other interested parties regarding the type of information to be asked for, and it was inevitable that some questions would arise later which might have been gone into in greater detail. This, however, had to be accepted as the price for getting any information at all.

Interrogation was carried out at three P.R.Cs:-

No. 106 P.R.C. at R.A.F. Station Cosford, for all British, Allied and Colonial personnel.

No. 11 and No. 12 P.D.R.Cs at Brighton and Hove, for Australian and New Zealand personnel.

No. 3 R.C.A.F. P.R.C. at Bournemouth for all Canadian personnel.

The following method of interrogation was used. The ex-P.O.Ws were received in parties of about 30. Each man was handed a printed pro-forma containing a few questions and space for a narrative of the last flight. A short explanation was given of the reasons for the questioning, and they were told how to fill up the form. As each man completed his form, it was read through hurriedly by the interrogator and, if necessary, a few supplementary questions were asked. This was a much less satisfactory method than that used originally for evaders and escapers, but it was all that was possible in the time. In one day, over 900 individuals were put through this process at Cosford; the information from this source was therefore not of the same quality as that obtained from evaders and escapers.

/Initially,

Initially, officers from the O.R.S. carried out the interrogation, but owing to shortage of staff it was immediately found necessary to make other arrangements - R.A.F. Intelligence officers being made available by Command. One Squadron Leader and five other officers were posted to Cosford, and two officers to each of Bournemouth and Brighton/Hove. O.R.S. officers were also made available when required, and at one period the interrogation staff at Cosford was as high as 14 persons.

The O.R.S. interrogation commenced on 11 April 1945, and was stopped on 22 June 1945, as it was not considered worthwhile to keep on a staff for the very reduced flow of ex-P.O.Ws. During this time over 10,000 Bomber Command aircrew ex-P.O.Ws were interviewed, the figure being approximately 96 per cent of the total in this category who had passed through the P.R.Cs.

The information given in these questionnaires was then prepared for analysis. This was done by means of the Hollerith punch card system by which a 'master' number code system was drawn up covering all the specific points of information likely to be obtained. Each story was then examined and coded in the appropriate manner, all stories relating to one aircraft being treated as one. After checking and cross-checking the numbers were then registered on a card by punching holes in appropriate spaces. By feeding these cards through a special sorting machine any desired combination of information allowed for in the coding system could be obtained.

This was a laborious job involving a staff of from 15 to 30 coders for approximately six months. On completion, the system would allow of the answering of specific questions provided these have been covered by the original Master Code system. Any answer produced from this source was, however, subject to bias in favour of the less serious causes of loss, as only incidents from which there was at least one survivor story were covered.

Variation of Loss Rate with Type of Aircraft

Among the many factors which influenced the overall loss rate on a given operation was the composition of the force. Bomber Command always consisted of a variety of different aircraft and from the beginning of the O.R.S's activities attention was paid to the variation in the loss rate between different types of aircraft. The different types of aircraft were nomally distributed by groups. Some groups had only one type, while other had two types. The same type of aircraft was also to be found in more than one Group.

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The difference in the loss rates was of great interest to many authorities including the Air Ministry, Ministry of Aircraft Production, and the Ministry of Production. It was clearly important to determine whether the differences were statistically significant and to ascertain the reasons for the differences.

It was apparent in 1941 that the loss rate of the Whitley was greater than that of the Wellington and the Hampden. One of the major differences between these types was the engines. The engines of the Whitley were liquid cooled, while those of the Wellington and Hampden were air-cooled. Theoretically, the vulnerability of liquid-cooled engines was greater than that of air-cooled engines and this was thought to be the most likely explanation. The differences in performance and size were not considered to be important factors although exhaust visibility which was greater in the case of the Whitley and would therefore lead to easier interception by fighters could not be ignored. The theory of engine vulnerability was supported by the fact that Wellington IIs, which had liquid-cooled engines had a greater loss rate than the Wellington Is. This question of engine vulnerability was of great interest particularly in the days of twin-engined aircraft, and the matter is discussed in detail in Chapter 19. Messrs. Rolls Royce naturally became very concerned at the results, and at a later stage in the war all Merlin engines damaged by enemy action were forwarded to the firm for detailed examination to see if anything could be done to reduce their vulnerability.

In connection with this question it is of interest to record the statistics for losses over the period May to December 1941.

Liquid-cooled Engines		Air-cooled Engines	
Wellington II	3.08%	Wellington I	2.54%
Whitley	3.77%	Hampden	2.43%
Manchester	4.8%	Stirling	3.7%
Halifax	4.5%		

The number of sorties flown by the Manchester and four-engined Halifax and Stirlings to which the above statistics relate were admittedly very small but the same trend is apparent. The fact that the four-engined aircraft had higher losses than the corresponding twins was due to inexperience in operating these types. In fact, during the next few months /the

the Stirling loss rate became the lowest of any type and remained so for some time.

There was no doubt that the inferior flame damping arrangements on the Whitley was a contributory cause to its higher loss rate and great importance was attached to improving it. Much effort was expended by the M.A.P. on the development of better flame dampers but no great success was achieved. Incidentally, the flame dampers in the Stirlings were very good.

Once a bomber was shown to have sustained a higher loss rate than the average the obvious remedy was to discard it and cease production. This step could unfortunately not be taken without seriously affecting the intensity of the offensive and although future production could be influenced it was necessary to continue operating the inferior types.

In connection with the analysis of Whitley losses it was shown in Bomber Command O.R.S. Report No. 43 (1) that they increased relative to other types whenever the target necessitated crossing the searchlight belt, whereas against targets which did not involve crossing the belt, the losses were roughly the same as for other types. This supported the general view that an important contribution to the higher losses sustained by the Whitley was its lack of manoeuvrability.

The statistics quoted above indicated that the Manchester, which was coming along as a replacement to the Whitley, was not very promising. In the early months of 1942 no improvement on the early figures appeared, whereas the teething troubles of the Stirling were soon overcome. This was a serious matter and in Bomber Command O.R.S. Report No. 44 (2) a comparison was made of Manchester and Stirling loss rates. It was found that on nearly all groups of targets the Manchester sustained a considerably higher loss rate. Even on coastal targets in occupied territory where the loss rate was normally very small this aircraft sustained 3.8 per cent over the period September 1941 to March 1942. Such evidence as available indicated that the difference in loss rates of the two types was due to enemy action and therefore to the different vulnerabilities. There were two main differences; first the Manchester had only two liquid-cooled engines, whereas the Stirling had four air-cooled engines and, secondly the Manchester had two large

/petrol

(1) A.H.B./II/69/184.
(2) A.H.B./II/70/387.

petrol tanks whereas the Stirling had 14 small tanks. There was little doubt that these two important factors accounted for the difference in loss rate. The O.R.S. regarded compartmentation of the petrol tanks of great importance in connection with future types of aircraft. Clearly, the greater vulnerability of a liquid-cooled engine would be less important in the four-engined aircraft with which the Command would in future be equipped.

As the number of heavy bombers increased in the Command statistics regarding their losses become more reliable. The experience of the O.R.S. had shown, however, how dangerous it was to consider merely the monthly figures which were widely published. In order to make a proper comparison it was essential to take into account such factors as target, weather, and experience of the crews. Even so the overall statistics would indicate that a closer examination was desirable and from these it became apparent in early 1942 that all was not well with the Halifax. A comparison was made in Bomber Command O.R.S. Report No. 48 (1) between the loss rates of Stirlings and Halifaxes for the period July 1941 to June 1942. There was no doubt that the loss rate of the Halifax was about 50 per cent greater than that of the Stirling. On lightly defended targets there was no appreciable difference and it was concluded that the difference was entirely due to enemy action. It was noted that Halifaxes reported fewer combats than Stirlings, they reported fewer damaged by fighters but had about the same flak damage rate. This clearly suggested greater vulnerability to fighter attack and might well have been associated with the far greater visibility of the Halifax exhausts and its rather doubtful stability in making evasive turns.

Investigations to improve the flame damping were put in hand and consideration was given to the stability problem by the designers. As a result Halifaxes were later fitted with modified rudders. By the end of 1943 a sufficient number of sorties had been flown by Halifaxes fitted with modified rudders to enable an assessment to be attempted of its effect on the loss rate. A very searching investigation into all possible factors, however, failed to find any diminution of the loss rate due to the modification (Bomber Command O.R.S. Report No. S.114).(2) It should be recorded, however, that it was the general opinion of pilots that the modification improved the flying qualities of the aircraft. /In

(1) A.H.B./II/70/328.
(2) A.H.B./II H/241/22/14.

In the meantime, the losses of the Lancaster did not escape examination, for the Air Ministry had noted from the overall statistics issued by the War Room that the losses of Lancasters appeared to be approaching that of other types. There was no doubt that this aircraft which had been markedly superior in its loss rates since its introduction appeared in the spring of 1943 to have descended to the common level. The situation was examined by the O.R.S. and it was found that the trend could be partly explained by the fact that squadrons equipped with this aircraft were frequently engaged in more hazardous operations than the other types. (Bomber Command O.R.S. Report No. 69).(1)

Throughout the war it was always the case that one type of aircraft in Bomber Command had a higher loss rate than the others. For example, when the Stirling was the only heavy bomber, it had a much lower loss rate than the medium bomber, but as Halifaxes and Lancasters came along the Stirling became the Command's worst aircraft and at a later stage the Halifax was worse than the Lancaster. The Mosquito had the lowest loss rate of any, and the suggestion was made that a great expansion in the Mosquito force was desirable. The O.R.S. was not in favour of this proposal in view of the lack of room for navigational and bombing aids in the aircraft. The value of an aircraft to Bomber Command could not be judged entirely on loss rates. It was bombs on the target per casualty that really mattered, and there is little evidence of the bombing accuracy of the Mosquitos. They were, of course, essential to 'Oboe' operations and were a useful element in 'spoof' tactics. They also undoubtedly had a large nuisance value, e.g. they bombed Berlin nearly every night, but it seemed unlikely that a large force was worthwhile, particularly since to deliver the same bomb load many more aircraft and hence pilots and airfields etc. would be needed than in the case of Lancasters, even assuming the same accuracy. Further, no doubt a bigger force would attract more of the enemy's attention and certainly sustain higher losses.

It was a matter for speculation whether the lower loss rate of the Lancaster was due to the fact that the Halifax was more easily susceptible to interception and what the loss rate would have been had Bomber Command had a homogeneous force. There were a few operations on which only Lancasters were used and a comparison was made of their losses when operating alone

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(1) A.H.B./II/69/222

compared with those when they were operating in a mixed force. The results (Bomber Command O.R.S. Memo M) [1] showed that when operating alone the loss rate was increased by about 50 per cent and in fact appeared to be even higher than that of the mixed force. This was no doubt partly due to the lower level of saturation of the defences due to the small forces engaged but it seems very likely that the lower losses of the Lancasters on general operations was due partly to the presence of lower performance and more visible aircraft in the force.

Variation in Losses between Groups and Squadrons

Each group maintained its own careful watch on its loss rate and its O.R.S. representative carried out certain investigations. Among these were studies of the effect of operational experience on the loss rate which is discussed later on in this chapter. Comparisons were naturally made between the various groups although these were difficult to interpret since the types of aircraft were different. Nos. 4 and 6 Groups, however, were both equipped with Halifaxes and in an investigation made in 1943 it was clearly shown that the losses in No. 6 Group were significantly higher than those sustained by No. 4 Group (Bomber Command O.R.S. Report B.147. [2] It was considered that this was most likely due to the lower experience of the group as a whole, since it had only been formed recently, and the lower experience of the crews. The report was sent to the Air Officer Commanding for consideration, and he requested the attachment of a member of the O.R.S. to carry out a more detailed study on the spot. (There was no resident O.R.S. representative at this group). A more detailed investigation was made and it was confirmed that the higher losses were due to inexperience and difficulties due to the formation of new squadrons and conversion to heavy bombers, which had reduced the amount of training done and instruction given within the individual squadrons. Appropriate steps were taken by the group headquarters to remedy the situation.

No. 4 Group, in their continual struggle to reduce their losses, suggested that one of the reasons that their Halifaxes sustained higher losses than the Lancaster might be because they were in the final wave of

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(1)
(2) A.H.B./IIH/241/22/12.

the attack. Actually, the plan of attack usually involved both Halifax and Lancaster aircraft in the opening as well as the final phase of the attack, and it was possible to compare the losses in the different waves. It was found (Bomber Command O.R.S. Memo) (1) that the later Halifaxes had higher losses than those in the earlier wave, but in both cases they were higher than the losses sustained by the corresponding Lancaster waves. While, therefore, the position in the attack might have some effect and it was certainly worthwhile getting the Halifaxes away from the target as early as possible, the main difference in loss rate could certainly not be attributed to their allotted place in the attack.

As regards losses of individual squadrons, it was well-known that many experienced bomber crews had their own ideas on the right tactics to employ to ensure survival, and although a general tactical doctrine was taught throughout Bomber Command, such individuals naturally had an influence on the tactics adopted by individual members of their squadron. An investigation was accordingly made to determine how the actual overall losses sustained by Lancasters in Nos. 1 and 5 Groups should have been distributed if the chance of any aircraft being lost was entirely independent of the squadron to which it belonged. The results given in Bomber Command O.R.S. Memo M 163 (2) show that while there was a slight tendency for extreme losses to be commoner and average losses to be rarer than expected by random chance, the tendency was quite insignificant. This analysis was repeated later for all squadrons in Bomber Command due allowance being made for the effect of type of aircraft, and it was found that apart from two particular squadrons, the losses were distributed as would have been expected from random chance (Bomber Command O.R.S. Memo M) (3)

The Effect on Experience on the Loss Rate

As indicated above, one of the factors affecting the loss rate was the experience of the crew and in the autumn of 1942, the O.R.S. started an investigation to determine the magnitude of this factor and to see if any change in the current policy for the employment of new crews was desirable. The need to allow crews to gain operational experience was well appreciated by the Command

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(1)
(2) 'Investigation into the losses of Lancasters by squadrons - June 1943.'
(3)

and the current policy was to send new pilots on a few operations as second pilot in an experienced crew in the first place and secondly to employ new crews on easy targets for their first few operations. It was desirable to determine the value of such experience and to check whether it was adequate to fit new crews for operations on main targets.

Attention was given first to Halifax squadrons since losses for this type were above the average. The results of the investigation given in Bomber Command O.R.S. Report No. B.116 (1) showed that the number of sorties which missing pilots carried out before becoming missing was dependent upon the number of second pilot or fresher trips they had made before becoming a captain or going on to main targets. Of those pilots who had become missing, those who had done under three second pilot or fresher trips had an average life of about two operations on main targets, but those who had done six second pilot or fresher trips had an average life of about eight operations. The investigation indicated that it was experience on flying Halifaxes which was important. As a result of this investigation, the Air Staff decided to give all Halifax pilots a series of training cross-country flights, two or three sorties as second pilots and two mining operations before sending them as captain on main targets.

An investigation on the effects of the pilot's experience on the casualty rate in No. 5 Group Lancasters (Report No. B.119) (2) was then made. It was found, contrary to the case of the Halifax, that the missing rate was independent of operational experience. It was pointed out that the missing rate of the Lancaster was at that time 2.9% and the chance of surviving 30 operations was therefore about 42%.

A further investigation into the effect of experience on No. 4 Group Halifax losses was made in May/June 1943, in order to discover whether the position had changed since the previous investigation, but it was found that the casualty rate of pilots making their first two or three sorties in No. 4 Group Halifaxes remained high compared with that of more experienced pilots. Bomber Command O.R.S. Report No. B.160 (3) suggested that the effect could possibly be reduced by increased initial training in crews of the Halifax and by improving the handling qualities of the aircraft.

/Investigations

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(3) A.H.B./IIH/241/22/12.

Investigations by the O.R.S. representative at No. 5 Group had shown that there was a slight tendency for the loss rate to rise and then fall again during the middle of the operational tour, and the Air Officer Commanding No. 5 Group drew attention to this apparent trend for losses in No. 5 Group, and recommended refresher training in the middle of a tour. The O.R.S. was asked to investigate the matter for the Command as a whole and arranged for all Groups to render monthly returns, divided by type of aircraft, and giving for each major operation the number of sorties, early returns, crashes, attacks and combats, for each stage of crews operational experience. These returns were consolidated each month by the O.R.S. and separate notes issued for December 1943, and January and February 1944. After the March figures had been received, the returns were discontinued and a thorough analysis for all the four months was issued in Bomber Command O.R.S. Report No. S.187.[1] The investigation confirmed the higher missing rate amongst inexperienced crews and found that their crash rate, early return rate and combat rate was also high. The tendency for the loss rate to rise above the average just after the middle of the first operational tour, was also confirmed, but was not found to be so serious as had been suspected by No. 5 Group. The report stated that it was a matter of opinion how far training can be a substitute for operational experience, but that if there was any remedy for the high loss rate of inexperienced crews, it could only lie in increased and improved training. Accordingly, it was recommended that efforts should be made to increase the verisimilitude of operational training, and in particular that more long practice flights with fighter affiliation should be regularly included.

A new technique of analysis was developed for the above investigation. Each major operation was divided by operational group, type and mark of aircraft. These divisions were further sub-divided into ~~two~~ five operational experience classes (0-5 Operations, 6-11 operations, 12-17 operations, 18-23 operations, 24-30 operations.) For each operation a separate missing rate was calculated for each division. The expected missing rate for each division was also calculated from the overall loss rate and the number of sorties flown in each experience class. If experience had no effect then this expected number would be equal to the actual number missing. The difference between these two figures thus serves as /a

(1) A.H.B./IIIC1/54/17(B).

a measure of the effect of experience, and by treating each operation and division separately the effect of different types of operation was largely eliminated.

Another investigation which brought out the importance of operational experience was made in response to a request from Air Ministry, to determine the maximum wastage rate a bomber force could stand during a sustained period of operations. The results were given in Bomber Command O.R.S. Memorandum No. M.144. (1) This investigation considered the cases in which types of aircraft had to be withdrawn from operations and pointed out that any rise in the casualty rate above a certain level is likely to diminish operational efficiency because of diminution produced in:-

(a) The general level of experience.

(b) The flow of operationally experienced instructors.

(c) The supply of suitable officers available as squadron and flight commanders and for specialists duties within the squadron.

The investigation showed that the permissible loss rate must be limited by the necessity of having a sufficiency of survivors at a late stage of the operational tour, and gave figures for the percentage of crews that survived a tour for a number of different average wastage rates. It concluded that a wastage rate in excess of 7 per cent could not provide sufficient survivors to maintain efficiency in operations.

Aircrew Casualties directly due to Enemy Action in Bombers returning from Night Operations

There was a feeling in the Command that personnel casualties were high and an investigation into the casualties among aircrew personnel directly due to enemy action was therefore made in February 1943 (Report No. S.77) (2) All available data was consulted, including medical officers' reports, raid reports, Flying Battle (F.B.) casualty signals and casualty forms. It was therefore possible to establish the circumstandes of almost every incident. It was found that the number of casualties in returning bombers was low, and that there were, in fact, on the average 1,013 man sorties per casualty in returning bombers due to flak, and 1150 man sorties per casualty due to fighters. The number of casualties per aircraft damaged due to flak was 0.07 and 0.05 per aircraft damaged by fighters.

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(2) A.H.B./IIH/241/22/3.

These figures did not vary greatly between various types of aircraft. Analysis showed that the number of aircraft lost primarily due to death or severe injury to the pilot must be very small. About 20 per cent of all casualties were fatal or dangerous.

The subject of casualties amongst aircrew personnel directly due to enemy action was considered again in January 1944 when there was a widespread feeling, especially amongst the general public, that bomber crews ought to wear suits that would protect them against flak. It was felt that as the Americans were supplied with special armoured clothing, the British aircrews should be given the same protection. Analysis showed that the figures for casualties per man sorties were still low, 1,673 man sorties on the average being made for every man returning injured due to flak, and 1,309 for every man returning injured due to fighters. The casualties per aircraft damaged were more or less unchanged from the previous analysis. The investigation showed that the frequency of casualties amongst aircrew personnel was very small and had been unaltered by the removal of the main armoured bulkhead (see Chapter 19). It concluded that the use of the American type of flak jacket would only be effective in preventing one moderate or slight casualty per 100 man sorties, and that in view of its weight, with the fatigue it would produce, would be likely to do more harm than good. The paper also concluded that the American flak helmet might have prevented one head injury per 7,000 man sorties, and its use might be justified if it was not too heavy and cumbersome, if it did not produce fatigue, and if the aircrew wished to use it. As a result of this investigation it was agreed that body armour should not be manufactured for aircrew personnel.

Further examination was made of the desirability of issuing crews with body armour when daylight operations started. However, it was still found that owing to the weight of the equipment, more aircrew personnel would be lost per unit weight of bombs dropped on Germany if the body armour were used than if it were not (Memorandum No. M.146) (1)

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(1) A.H.B./IIH/241/22/3.

Casualties Sustained in Crashes not due to Enemy Action among Aircrew over this Country

The casualty rate of different crew positions in non-enemy accidents over this country was considered in July 1944, with particular reference to casualties amongst air gunners. It was found (Memorandum M.145)[1] that casualties among pilots and gunners were somewhat greater than those among the rest of the crew, that aircraft of different types showed similar percentages of different categories of accidents, and that casualties per accident and per crew position showed no obvious variation between aircraft types.

The Fate of Aircrew in Aircraft that became Missing

In September 1943 a letter was received from the Air Officer Commanding No. 1 Group in which it was pointed out only a very small proportion of aircrew lost on night operations succeeded in returning to this country or became Prisoners of War, and that these proportions were decreasing. Fortunately, this question had already been considered by the O.R.S. in Memorandum No. M.137,[2] 'An Examination of two Special Sources of Information on the Causes of Our Losses', and the O.R.S. was able to advise the Air Staff that it appeared that the proportion of lost Lancaster crews who were taken prisoner was rather less than for other types, and that the decline reported of the percentage of aircrew evading capture and returning to this country was probably due to the increasing use of Lancasters in the bomber force, to the German occupation of Southern France, and to the high proportion of bomber penetrations which had recently been made deep into Germany. A very extensive analysis of the available information as to the number of P.O.W's and the number of crews that were successful in returning to this country was then made (Report No. S.122).[3] This report pointed out that the proportion of missing aircrew that survived to become P.O.W's was 11 per cent for Lancasters, 17 per cent for Stirlings and 29 per cent for Halifaxes. The low rate for Lancasters was thought to be due to the fact that it was more difficult to escape from that aircraft owing to the greater difficulty in moving about in ~~this narrow aircraft,~~ the narrow fuselage, to the small

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(2) A.H.B./IIH/241/22/3.
(3) A.H.B./IIH/241/22/14.

forward compartment, and to the poor rear escape hatch. It was also thought possible that the Lancaster was more liable to break up in the air and that the higher flight conditions might increase the difficulties of escape after the removal of the oxygen mask. It was suggested that consideration should be given to the possibility of fitting a rear floor escape hatch to the Lancaster, and that all escape hatches should be re-examined with a view to redesigning to prevent jamming. It was also suggested that more training and practice in emergency drill would be beneficial. A re-write of the O.R.S. paper, giving the results, was later issued by the A.S. and R Branch of the Air Staff, and given a wide circulation.

Attention was later specially drawn to the serious difficulties which frequently occurred owing to the jamming of the front escape hatch as when it was being thrown out it tended to twist itself perpendicular to the airstream and to jam. The importance of adequate means of escape from bomber aircraft was stressed in a letter from the O.R.S. to the Deputy Director of Accident Prevention on 4 January 1944. The figures for survival were given and it was suggested that the difference was largely due to the difference of ease of escape from the two aircraft. Since 1,641 Lancasters, each containing seven aircrew, were missing in the period under consideration it would appear that at least 2,125 lives were lost due to this cause.

Ditching

An analysis of the incidence of aircraft ditching was made in October 1944 (Bomber Command Report O.R.S. Report No. S.188) [1] It was found that the number of ditchings, which became known in this country due to radio transmission from the ditching aircraft, or through being seen from the air, was distributed at random throughout the sea between this country and the enemy coast, but that there were in addition a large number of ditchings taking place near the coast of this country which had became known as the

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(1) A.H.B./IIH/241/22/14.

crews were either picked up by the coastal shipping or were seen from land. The inescapable conclusion was reached that many more ditchings must be taking place than the Command had been aware of. In consequence of this report, a letter was sent out to all aircrew impressing upon them the urgent necessity of transmitting when they thought there was any likelihood of their being forced to ditch, and steps were taken by the signals staff to ensure greater certainty of messages sent out being received.

Bomber Manoeuvres

The manoeuvres executed by bombers, particularly in the target area and on encounters with flak or enemy aircraft en route, were of great interest in the study of bombing accuracy and the effectiveness of evasive action. Such information was also needed to enable the degree of stabilisation of H2S to be determined. The first evidence was obtained by 'N' Section of the Central Interpretation Unit who developed a technique for deducing the form of manoeuvres in the target area from a study of the night photographs taken by bombers at the time of bomb release. This technique was worked out in 1942 and was applied to a small number of sorties on various operations during 1942 and 1943. The results were fragmentary, and suffered from the serious disadvantage that, with the camera cycle normally used, information could only be obtained concerning the manoeuvres taken after bombing, whereas the most important time was of course the period immediately before bombing. In May 1943 it was therefore suggested by the O.R.S. that the camera cycle in certain aircraft, and in particular in aircraft of the Pathfinder Force should be modified in such a way as to provide information covering the period of the run-up to the target; a simple method of making the modification was also put forward. This modified camera cycle was accepted by the Command, and on 22 May 1943 each group was instructed to make the modification in all the aircraft of one of its squadrons.

The diagrams obtained by the Central Interpretation Unit from the films exposed with the modified cycle were analysed by the O.R.S. and the results

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~~(1) A.H.B./II/39/1/1.~~

are given in Memorandum M. [(1)] They confirmed the view which the Command had taken since the spring of 1943, that the evasive action taken by bombers in the target area was of a kind which would not reduce losses due to flak and if practised on the bombing run would prevent accurate bombing.

The necessary information having been obtained, the use of the modified cycle was discontinued throughout the Command on 28 October 1943. This was due mainly to the objection which had been raised by the Air Officer Commanding No. 8 Group, who claimed that the modified cycle distracted bomb-aimers during their search for the target. He felt, however, the need for obtaining further information on aircraft manoeuvres and asked that his aircraft might be equipped with the Type M Automatic Observer which had been developed by the Royal Aircraft Establishment.

This device, which could be installed in any aircraft equipped with blind flying instruments, produced a record of the movements of the aircraft during any required period not exceeding eight minutes. The record produced by the instrument was in the form of a cinematograph film, in which frames consisting of a photograph of a complete blind flying instrument panel were taken at intervals of one second. This form of presentation was not particularly well suited to the purpose of the O.R.S. but as there was little chance of obtaining a better instrument in reasonable time, it strongly supported its introduction.

It was agreed that the first ten observers off production should be given to No. 8 Group, and carried by bombers on operations so as to provide records of aircraft manoeuvres during a period of eight minutes up to and including the moment of bomb release. The first operational sortie carrying an observer was made on 2/3 October 1943, the target being Munich. The films exposed in the Auto Observers carried by No. 8 Group, were despatched to the O.R.S. for analysis. There were also a few films taken at the Bombing Development Unit in a Halifax performing standard manoeuvres, which were intended to assist in the analysis of the operational films. Before anything could be done with the films, it was necessary for the O.R.S. to reduce the results to graphical form. The method used in producing the

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graphs is fully described in 'Bomber Command Armament Training Notes, Bombing Note No. 8', published by the Training Branch on 31 December 1944. The graphs when produced were distributed to the Royal Aircraft Establishment, No. 8 Group, and the M.A.P. The O.R.S. intended to make a full-scale analysis of the results, but unfortunately the process of making and reproducing the graphs was laborious and slow, partly owing to the inherent disadvantages of this photographic type of record and partly owing to the poor quality of a large proportion of the films. It was impossible to produce the graphical records at the place and time at which they would have been most valuable, namely on the station from which the aircraft carrying the recorder operated, and within one or two days of the time of the operation recorded. The records were therefore not of much direct assistance to the individual squadrons, and crews who carried the observers, since the graphs usually arrived too latefor any clear memories to be retained of the conditions under which the films were taken.

The Auto Observers used in heavy aircraft of No. 8 Group produced 54 readable films, which were reduced to graphical form and published, the last being taken on 17/18 June 1944. The first 35 of these records were used by the R.A.E. in order to find how far flying conditions affected the accuracy of the release point as calculated by the Mark XIV bombsight; the results of this analysis were published in March 1944 as R.A.E. Technical Note No. Inst/844. A similar detailed analysis was not undertaken by the O.R.S., since it did not appear that quantitative estimates of the various quantities recorded on the graphs would be of any value to the Command. The graphs were, however, valuable to the O.R.S. in providing a general picture of the type of manoeuvres carried out by bombers in the target area, so that arguments regarding the advantages and disadvantages of evasive action could be placed against a realistic background of information. In particular, the results were used in estimating the risk of collisions between bombers in the target area, and showed that the amount of evasive action taken was such as seriously to increase this risk. In the main, the Auto Observer graphs had the effect of strengthening the case for the policy of reducing evasive action over enemy territory, which policy the Command had been trying to enforce since the spring of 1943.

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In July 1944 it was suggested by the O.R.S. that the auto observer should be used to determine the magnitude of the flying errors of Mosquitos making a controlled bombing run with Oboe. It was a matter of some importance to decide whether the inaccuracies of Oboe bombing could be attributed to flying errors, or whether some unknown source of error was involved. Accordingly, a number of observers were issued to Nos. 105 and 109 Squadrons, with a modified form of D.R. compass dial to give greater accuracy in the reading of heading. The films taken were read by O.R.S., and the readings were set out in tabular form since greater accuracy was required than could conveniently be achieved in a graphical reproduction. The tables of readings were then analysed by the O.R.S. with the assistance of the Deputy Directorate of Science (Air Ministry), and the results of the analysis were published in Report No. S.202.[1] It was shown in that report that flying errors did in fact account for a large part but not quite all of the otherwise unexplained operational bombing inaccuracies. Later on, the tables of readings produced by the O.R.S. were analysed in greater detail by the A.W.A.S., and formed the basis for A.W.A. Report No.58, ~~(2)~~ which dealt with the operational performance of Oboe from a more theoretical point of view. The making of Auto Observer records in Mosquitos was finally discontinued at the end of October 1944.

In July 1944 all the existing auto observers were installed in Mosquitos of No. 8 Group, and it was decided that the replacements which were in production at the R.A.E. should not begiven to No. 8 Group but should be distributed among the other groups. Each group was to receive in the first place two Auto Observers, which were to be installed in heavy bombers so as to provide a picture of target manoeuvres among the main force similar to that obtained from No. 8 Group. The main force records began in August 1944, and the films were read by the O.R.S., and the results distributed as before in the form of graphs. Up till January 1945 fifty of these graphs were issued, covering both night and day operations. The release point errors caused in the Mark XIV bombsight computor by the manoeuvres recorded in these graphs were analysed by the R.A.E., the results being published in R.A.E. Technical Note No. Inst/901. ~~(3)~~ The analysis

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(1) A.H.B./IIH/241/22/14.
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was similar to the previous R.A.E. analysis of the No. 8 Group graphs, and showed that the bombing errors due to the disturbance of the bombsight by evasive action were very considerably smaller in the main force than they had been in No. 8 Group a year earlier. Apart from this work by the R.A.E. the graphs were not studied in detail, but were used by the O.R.S. to keep a current check on the nature of evasive manoeuvres in the target area.

In view of the labour involved in interpreting and reproducing the auto observer records, and the delay caused by concentrating all this work at the O.R.S., it was decided in November 1944 that the main force groups should read their own films. An instructional note was written by O.R.S. to enable the groups to take over the work. In January and February 1945 a final 14 records were produced by the Groups under the new system, and the graphs checked by the O.R.S. The number of auto observers in service was, however, decreasing through operational wastage, and new production had been stopped because the priority of the auto observer was not high enough to justify a curtailment of production of the Stabilised Automatic Bomb-sight Mark IIA with which it was competing. Thus, the making of Auto Observer records gradually petered out and eventually came to a stop in March 1945. A short summary of the trend of bomber manoeuvres up to that date was written by the O.R.S. at the request of the M.A.P., in order to assist the designers of the new Navigation Bombing Computer which was then in course of development. This summary, given in Memorandum No. M. entitled 'Information from Auto Observer Records and other Sources concerning the Amount of Evasive Action taken by Heavy Bombers on Operations',(1) includes the main conclusions which the O.R.S. was able to draw from the whole series of Auto Observer graphs.

Considering that the Auto Observer was practically the only source of detailed and objective information concerning the behaviour of bombers on operations, it is regrettable that so little real use was made by the O.R.S. of the information which it provided. It may be of value to enquire why this was so, with a view to formulating future requirements for devices of a

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similar kind. The most important failings of the Auto Observer were its unsuitability for large-scale use and its lack of adaptability to varying requirements. Both these faults arose from the fact that the instrument was designed for use in a research establishment for a specified purpose, and was never intended to be a standard operational equipment. For an Automatic Observer to be used on a large-scale in operational aircraft, it was essential that the instrument reading should be recorded directly as traces on a graph, and that there should be a high degree of flexibility in choosing the speed and duration of the record and the combination of instruments to be recorded.

The Effect of Icing on Bomber Command Operations

The first main investigation undertaken by the O.R.S. into the effect of icing on Bomber Command operations was an attempt to find the effect of icing conditions on the percentage of aircraft missing. The results are given in Bomber Command O.R.S. Report No. 42 [1] which gives the percentage of sorties of aircraft of various types missing on icing and non-icing nights. The data showed that the proportions of sorties missing have been about the same when icing conditions were present or absent, except in the case of Wellington Ic's before December 1941, whose losses were much higher under icing conditions. This difference disappeared after the introduction of alcoholised fuel, in December 1941. The other types of aircraft in use in the Command had always had effective means for preventing carburettor icing, but the Wellington I'c's did not before the introduction of alcoholic fuel. It therefore appeared that the prevention of carburettor icing was very important and that this could be done by the use of alcoholised fuel. It may be mentioned that interrogation of repatriated Prisoners of War after the war showed that a large number of Wellington Ic's were, in fact, lost due to engine icing, and that few aircraft of other types were lost in this way.

The next main icing investigation carried out was an attempt to discover whether or not 'Kilfrost' de-icing paste was advantageous. This paste was in general use throughout the Command, although some discretion

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(1) A.H.B./IIK/10/46B.

was allowed to squadron commanders. The substance had, however, to be spread evenly over the aircraft and this required a large number of man-hours. The substance consisted of a paste to be applied smoothly to the edges of the wings and control surfaces, the idea being that any ice forming on the paste would break away with some of the paste before any great weight of ice had been built up. Also, the presence of soluble salts in the paste was supposed to lower the freezing point of the water impinging thereon and so reducing the incidence of ice formation. Preliminary experiments in its discontinuation showed no significant effect, so sanction was obtained for a large-scale experiment whereby half the operational force would use 'Kilfrost' on the leading edges of all wing and control surfaces, while the other half would use it on the leading edges of control surfaces only.

The preliminary results showed that there was no significant difference in the percentage of abortive sorties in the two classes, and it was therefore suggested that, since no obviously adverse effects were accruing from the use of 'Kilfrost' on the control surfaces only, and since the data available was still inadequate for a thorough test, it would be worthwhile continuing the investigation for some time. This was agreed.

After a further period it was still found difficult to draw firm conclusions, but it was felt that if 'Kilfrost' had been advantageous it would have shown a definite result. In view of the disadvantages in its use - weight penalty of 30 pounds, manpower requirement of 15 hours, difficulty of smooth application, possibility that rough application might disturb the airflow and assist ice accretion, and no apparent advantage under conditions of heavy icing - it was recommended (Bomber Command O.R.S. Memorandum No. 133, 'The use of "Kilfrost" De-icing Paste on Operational Aircraft') [1] that:-

(a) the use of "Kilfrost" paste on the leading edges of all mainplanes be discontinued

(b) the use of "Kilfrost" paste on the leading edges of control surfaces be continued.

In October 1943, a general report on icing was prepared covering the period October 1941 to June 1943. The basis of this work was to separate /operational

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operational nights into those on which icing of any type was reported and those on which none was reported. Data were obtained from operational records, and special ice accretion reports concerning sorties, aircraft missing, G.C.I. activity, attacks, flak losses, reasons for abortive sorties, types of defect and types of icing, temperatures, methods of escape from icing conditions. This information was treated in a variety of ways. Owing to some doubt regarding the soundness of the original basis, i.e. the split into icing and non-icing nights and to other difficulties, this report was not issued for general circulation. The results of the investigation, which were given in Bomber Command O.R.S. Memorandum No. M.134,(1) were as follows.

(a) The abortive rate was greater on icing than on non-icing nights and this difference was somewhat greater in winter than in summer.

(b) Examination of the somewhat limited evidence available did not show that the enemy defence activity, either in night fighters or flak, had been markedly affected by icing conditions. There was also no obvious tendency for losses to either night fighters or flak to increase under icing conditions.

(c) A large number of different troubles were reported by aircrews on icing nights, but these were re-grouped wherever possible according to the most likely type of countermeasure which might have been taken. The results showed the need for improvement in the following fields:- wing icing, engine and propeller icing, lubricant and hydraulic fluid troubles due to increasing viscosity at low temperatures, pitot head icing, and windscreen icing. Wing icing was the most severe, amounting to over one third of reported cases, but lubricant and hydraulic troubles, engine and propeller icing and pitot head icing were also of some magnitude.

(d) The Lancaster was shown to be in general less affected by icing than other types of aircraft. The Stirling was more affected by wing icing, probably owing to its lower maximum height which could often render it unable to make use of climbing as a method of evading icing conditions. Halifax aircraft showed a high increase in the abortive rate on icing which was probably due in the main to wing icing.

(e) A consideration of the action taken by different types of aircraft when icing conditions were encountered again, showed the Lancaster to be somewhat superior to the other types.

(f) The temperatures at which various forms of icing occured were examined and a number of troubles were reported down to temperatures as low as minus 23°C.

A number of attempts were made to find the proportion of aircraft lost due to icing at various times, but except for the investigation mentioned earlier, in which it was found that a large number of Wellington Ic's were lost, very little direct evidence of losses due to this cause was found, and it was concluded that they must be very small, as otherwise such evidence

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would have been available. This question together with others relating to the effects of icing on bomber operations, was considered at an Air Ministry meeting held on 19 April 1944. At this meeting the O.R.S. stated that members of the crews of some 150 aircraft lost on bombing raids had been interviewed in connection with the investigations into the causes of losses. In no case was icing the cause of loss. There was no other evidence of losses due to icing recently, although such losses did occur up to 18 months prior to this conference, especially of Wellingtons. It was considered that the performance of the heavy bombers with engine de-icing as was then provided was such that not more than 1 per cent of all losses could be due to icing. The policy of Bomber Command was to avoid flying in icing cloud conditions, but if it became necessary for the aircraft to fly in all weathers, the icing losses would undoubtedly increase.

Various attempts were made to assess the weight of de-icing equipment that it was economic to carry in bomber aircraft, and the results of some of these investigations were given in Internal Memoranda Nos. 135 [1] and 136.[2]

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(1) A.H.B./IIH/241/22/3.
(2) A.H.B./IIH/241/22/3.

CHAPTER 17

RADIO AIDS TO THE DEFENCE OF BOMBERS

The Scope of Radio Aids

The first year of the European War demonstrated to Britain the great value of radar as a defensive weapon. Photographic reconnaissance and listening watches revealed that the enemy had also realised the possibilities of radar aided defence and therefore, when it became possible to prepare an air offensive, thought naturally turned to means of neutralising the enemy's radar system and to applying radar searching methods to the protection of bombers.

During 1941 the enemy was still capable of substantial bombing raids against this country and there was great reluctance to take determined action against enemy radar lest retaliatory action should inflict a serious handicap on our own defences. In 1942, the relative power of offensive action in the air swung decidedly into this country's favour and a campaign of radio-countermeasures began. This gathered strength with the progress of the air-war and, changing in its direction of incidence in order to meet enemy developments, continued, to the end of the war.

The aim of the radio-countermeasures was to deny to the enemy radar installations the information which they sought and to prevent the passing of information by wireless means. In addition, during 1943, radar search apparatus was fitted into bombers, in order to provide aircrews with warning of imminent hostile action against them, and into fighters used for bomber support. Radio aids provided specifically as aids to navigation could also clearly have an effect on the defence of bombers since they could assist in maintaining the high concentration of bombers in space and time which was shown to be a powerful tactical countermeasure against the enemy defences (Bomber Command O.R.S. Reports Nos. 9 (1) and 34 (2)).

Steps in the Development of a Radio Aid

In the introduction of radio aids for bomber defence the normal chain of development may be stated as follows.

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(2) A.H.B./II/70/163.

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(a) The provision of knowledge of the enemy's defensive system and of technical details of his radio and radar installations.

(b) Decisions of policy as to the parts of the enemy's system to be assailed.

(c) Technical development of the means to carry out the policy.

(d) Decision of what scale the effort should be and how it should be applied.

(e) Assessment of the results obtained by application of the measure.

These steps have not always followed the chronological order in which they are set down here, and frequently one step has not been clearly separated from another, but in one way or another all had to be made for each radio aid. Much of the contribution of O.R.S. to the various processes of development will emerge as detailed consideration is given to individual aids, but some broad generalities are more conveniently treated here.

Information about the Enemy's System of Defence

Obtaining knowledge of the enemy's system was largely an Intelligence responsibility. There were, however, opportunities for the O.R.S. to assist in some matters since from time to time useful information could be obtained from the observations of aircrew recorded either in their routine reports of operational flights or in special reports requested for a specific purpose. These reports, often appreciated cursorily by Intelligence, frequently required careful analysis to yield their full and true results and this analysis was an appropriate O.R.S. function. An important example of this work which had a strong bearing on the determination of which radio aids offered the highest returns was the assessment of the relative contributions of the various causes of loss of bombers to the total wastage (e.g. Bomber Command O.R.S. Report No. S.91 - 'Night Bomber losses on German Targets 1942').(1)

Design of Equipment

The design of apparatus was a matter entirely for the appropriate experimental establishments, T.R.E. and R.A.E. The O.R.S., however, performed a liaison duty interpreting difficulties in designing to the service and advising the experimental establishments on the expected conditions of operation.

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(1) A.H.B./IIH/241/22/14.

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Direction of Policy

In decisions of policy, concerning either general lines of progress or the scale and mode of application of a particular measure, the O.R.S. almost invariably had a part to play. Most of these decisions had to be based on an incomplete knowldge and frequently had to take into consideration that a device designed to confer a benefit might also have harmful effects. For example, it was extremely difficult to assess the benefit of an electrical airborne jammer for a type of enemy radar set because of uncertain knowledge of the enemy's reliance on that particular set, and the unknown risk that the enemy would use the jamming signal as a means of detecting and destroying its source. Therefore, decisions had to be based on judgments arrived at after full discussion.

Within Bomber Command, the responsibility for recommending action in the field of radio aids rested with the Signals branch, and the O.R.S. maintained a close liaison with the section of that branch dealing with radio-countermeasures. Discussions with T.R.E. either jointly with members of the Signals branch or alone also played an important part in arriving at sound judgments. Apart from these informal discussions on a day-to-day basis, more general consultations were pursued within a Radio-Countermeasure Committee set up within Bomber Command during 1943. This body comprised representatives of the Signals, Intelligence and O.R.S. branches with representatives of the Air Staff and of Air Ministry as occasion demanded. At the time of most active development of countermeasures that Committee met fortnightly. A similar Committee on Tail-Warning Devices (the radar sets carried by bombers to warn crew of the approach of other aircraft) was set up during 1944.

The special role of the O.R.S. in these discussions, in addition to putting ideas into the common pool and presenting assessments of the results of measures already in operation, was to present the facts gathered from all sources in a clear and balanced form so that the issues to be judged could readily be appreciated. This might be done verbally, but occasionally appreciations of the evidence were prepared in writing for discussion or, after the discussion, the conclusions arrived at with the evidence on which they were based were marshalled into convincing form

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for submission to the Air Staff or to Air Ministry. In considering the reports which follow on the work of O.R.S. on individual radio aids, this background of discussion must be borne in mind. Although an attempt has been made to make clear the specific O.R.S. contribution, some of the ideas and judgments referred to were inspired or coloured by discussion with other branches, while at the same time O.R.S. consultation helped in arriving at conclusions which are not included as O.R.S. contributions.

In addition to the deliberations within Bomber Command and at T.R.E., the O.R.S. was represented on the committees at Air Ministry, usually under the chairmanship of the Controller of Communications, which considered the development of radio equipment often in relation to its production. Owing to the difficulties experienced by production in meeting the rapidly changing demands made by radio-countermeasures, these committees had not infrequently to make decisions which involved the Command's policy and, on these occasions, the O.R.S. was able to assist the Signals branch in stating a case.

Assessment of Results

The assessment of the results obtained by radio aids to bomber defence devolved almost wholly upon the O.R.S. For some measures, e.g. the application of jamming to some of the enemy's methods of communication, some effect was made apparent immediately by the enemy's avoiding action. In general, however, the detailed analysis of a large mass of information was required. The methods used and difficultiesinvolved in the assessment will be described before detailed results of each class of countermeasure are considered. It may be said here that these difficulties were such that the conclusions, as has also been stated, had to be based on judgment of indications rather than on incontrovertible facts.

When in December 1943, No. 100 Group was formed in order to operate those of the countermeasures better applied by specialist aircraft, an O.R.S. representative was attached to the Group. He was able to pay special attention to the day-to-day problems of the Group while maintaining close liaison with the general investigations carried on at Command.

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Early Developments

The history of Bomber Command's radio-countermeasures has been dealt with in great detail elsewhere (Air Staff Operational Monograph No. 1 'Countermeasures to German Radar Defences' (1). The Director of Air Tactics First Draft, May 1944 'War in the Ether - Europe 1939-45 - Radio-Countermeasures in Bomber Command' - (2) Signals Branch Headquarters Bomber Command June 1945). The most convenient method in dealing with the O.R.S. contribution is to consider individually each device used so that its development from conception to demise or honourable retirement can be followed. It is, however, desirable to give a brief account of the enemy's defensive system in order that the functions of the special devices may be appreciated and to review the period before the introduction of specific measures.

At the request of the Air Officer Commanding-in-Chief Bomber Command in September 1941, the O.R.S. prepared an appreciation of the existing knowledge of enemy radar installations and of the proposals for countering them which were being developed (Report No. 4 ' Enemy R.D.F. and Bomber Command Night Operations'). (3) It was pointed out that there was a serious deficiency in our knowledge of the enemy's use of radar in controlling guns, searchlights and fighters, countermeasures against which were considered to be more necessary than against the better known enemy early warning radar. In forwarding the report to Air Ministry, the Commander-in-Chief requested that immediate further measures be taken to obtain more information on the lines which it suggested. The reply gave an assurance that the search for information on enemy methods and the development of countermeasures would be actively pursued. During the next few months much

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additional information was obtained. The means to secure it included a Commando raid on the enemy-occupied coast in order to capture a Wurzburg, the apparatus used to control anti-aircraft fire. Although there was still some anxiety about the initiation of a jamming war, development of means to counter enemy equipment was actively pursued at T.R.E. as details of the equipment became known.

As this activity brought the large-scale application of radio-countermeasures nearer to practicability, it became necessary to secure a firm policy in favour of a jamming campaign and to re-assess the priority of application. A memorandum was therefore prepared to this end (Bomber Command O.R.S. Report No. S.59 - 'The Advantages to be Gained by the Use of Countermeasures against Enemy R.D.F.')(1). The contribution of various causes of loss to the total wastage of bomber aircraft was first estimated, the main basis for judgment being the reports by aircrews of bombers seen to be shot down. The tentative allocation of losses reached was as follows.

	Percentage of Missing	Percentage of Total Wastage (Aircraft missing and written off)
Flak at Target	30% (2/3 while held in searchlights)	20%
Flak *en route*	15% (½ while held in searchlights)	10%
Fighter at Target	5% (½ while held in searchlights)	3%
Fighter *en route*	40% (¼ while held in searchlights)	26%
Not due to Enemy Action	10%	41% (including non-operational wastage)

It was considered that all losses to fighters *en route* and losses to flak unaided by searchlights were attributable to radar control. The control of searchlights was uncertain. The conclusion reached was that the potential saving by neutralising the enemy radar control was 60 per cent of the total wastage if searchlights were radar controlled and 30 per cent if they were not. A reduction of 50 per cent was regarded as a possible achievement. It was stressed that if the total bombing effort were controlled by aircraft wastage such a saving would result in a doubling of the effort, and that in addition

(1) A.H.B./IIH/241/22/12.

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the effectiveness of attack would be increased by the resulting higher level of experience in the crews and the reduction in distraction by target defences. The recommendation made was that the highest priority should be given to the development of radio countermeasures, those for use over the target being regarded as of first importance and those for use against ground control of fighters second. A copy of this report was forwarded to Air Ministry by the Commander-in-Chief with a request for the provision of suitable radio-countermeasures with the utmost importance and urgency.

The progress of technical development was reviewed about this time by T.R.E. (Report No. 5/R/69/MR 'Second Interim Report on R.C.M. Aids for Bomber Protection'), and the Command's request for urgent action generated in correspondence between Air Ministry and Command concerning practical possibilities which culminated in a conference held at Bomber Command on 6 October 1942. This conference of the Signals branch and O.R.S. of the Command with representatives from Air Ministry, under the chairmanship of the Senior Air Staff Officer, agreed that such countermeasures as were ready for application should be applied as soon as possible.

Organisation of the Enemy Defences at the Beginning of the Countermeasure Campaign

In the late autumn of 1942 when radio countermeasures became operational, the enemy had four main types of radar equipment to assist his defence. These were:-

Freya. On a frequency of 120-130 mc/s, a broad-beamed scanning system used primarily as an early warning set, but also as a putter-on for narrow-beamed ground equipments.

Wurzburg. On a frequency of 550-570 mc/s, a narrow-beamed system used for the control of anti-aircraft fire (G.L.) and it was thought probable, of searchlights (Searchlight Control (S.L.C.)).

Giant Würzburg. On a frequency of 550-570 mc/s, similar to the Wurzburg but more narrowly beamed, used for Ground Controlled Interception (G.C.I.). For this application, two of the sets were sited together, one plotting the course of the bomber and the other of a night fighter. Instructions to the fighter to guide the pilot towards an attacking position were passed by radio telephony, on a frequency within the band 3-6 mc/s.

Lichtenstein. On a frequency of 490 mc/s, an airborne aid for night fighters (A.I.). The Giant Wurzburg G.C.I. system could guide the fighter into visual range of the bomber under favourable conditions, but the Lichtenstein was often a necessary and always a useful adjunct to it.

The Freyas were deployed around the enemy-occupied coast to give continuous cover on single aircraft at 10,000 feet out to a range of 70-80 miles. Sets were also placed inland on the G.C.I. sites to help in putting the narrow beams of the Giant Wurzburgs on to targets. The Wurzburgs for gunfire and searchlight control were deployed in strength in the many gun-defended areas, while the G.C.I. sites were arranged in a belt round the northern and western approaches to Germany. Each pair of Giant Wurzburgs was used to control interception of bombers passing over a fixed area or 'box' of territory surrounding the site and contiguous with the 'boxes' of the next pairs of sites in the chain.

The sequence of events in the German system was that the Freyas secured early warning of the approach of a bomber force and alerted the defences. Fighters became airborne, if they were not already carrying out exercises, in the G.C.I. boxes and guns were manned in the gun-defended areas on the probable bomber route. In the G.C.I. belt the bomber was likely to be tracked first by a Freya, then by a Giant Wurzburg and then by the Lichtenstein carried by the fighter. There were thus three radar stages in the G.C.I. process open to countermeasures and, in addition, the radio communication between ground control and fighter, vital to the success of an interception, could be attacked. In gun defended areas the Wurzburg was the radar control both for prediction of blind fire or for the laying on of searchlights to allow data for gunfire to be obtained visually.

Brief History of Radio Countermeasures Campaign

The first attempt to counter enemy radar was applied unofficially and in an unorganised fashion by aircrews who gained the impression in 1940-41 that switching on their radar identification device (I.F.F.) embarrassed the enemy searchlight control. This idea was after investigation exploited in the first countermeasure deliberately aimed at the Wurzburg, Shiver, in October 1942.

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At the beginning of December 1942 countermeasure Mandrel was introduced to jam the Freyas. This was followed, partly no doubt as a consequence, by the enemy's introduction of other early warning sets, the Hoarding and the Chimney during 1943.

In July 1943 countermeasure Window was introduced as a counter to the Wurzburg and the Lichtenstein. This countermeasure was not an electrical device but consisted in the production of large numbers of spurious responses to the enemy radar by means of quantities of metal foil released from the bombers. Almost immediately afterwards, the enemy largely abandoned G.C.I. and took to directing fighters en masse by directions transmitted from the ground to areas where they might hope to contact the stream of bombers and find targets for themselves with their airborne radar. Neither type of Wurzburg, was, however, supplemented by other apparatus but both were used to plot the course of the bomber stream and were modified in various ways in attempts to overcome the effects of Window sufficiently for use in gunfire control.

In February 1944 an electrical jammer for the Wurzburg was introduced as Carpet II. The Lichtenstein was also attacked by means of electrical jamming applied from a ground station, Ground Grocer and an airborne jammer Grocer was also prepared. However, early in 1944, the enemy superseded the Lichtenstein by another A.I. known as S.N.2. When this was discovered in July, specially prepared Window was employed as a counter. Later, an electrical jammer, Piperack, was directed against S.N.2 by specialist aircraft of No. 100 Group.

In support of Operation Overlord, an extensive scheme of radio-countermeasures was employed. This included the jamming of the Freyas by an improved technique in using Mandrel and the production of simulated forces by the use of Window. After the invasion, the new Mandrel technique - the Mandrel screen - and Window-aided feints were used in support of bombing operations.

The enemy countermeasures during 1944 were almost wholly designed to make use of British transmissions as an aid to or replacement for his radar. Thus, an early warning apparatus, the Heidelberg, was introduced which used transmissions from the British C.H. system, measuring the path difference

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between pulses received direct and received after reflection from aircraft. An elaborate aircraft reporting system was set up in which ground stations searched for signals known to be characteristic transmissions of British bombers and were able by this means to obtain early warning of the approach of a bomber force and to plot its course continuously. In addition, night fighters were equipped with apparatus which enabled them to home on transmissions from bombers. The countermeasure to these methods was to restrict bomber transmissions, and became known as 'Signals Silence'.

For convenience a list is given below of the dates on which the various countermeasures and other defensive devices employed were introduced.

Dates of Introduction of Radio Aids

Radio Aids	Date of Introduction	Purpose
Switching on I.F.F.	late 1940	Interference with enemy searchlight control.
J Switch of I.F.F.	8/9. 7.42	Wurzburg jamming.
Monkey (later Shiver)	13/14.10.42	Wurzburg jamming.
Boozer	13/14.11.42	Tail-warning.
Tinsel	2/3.12.42	Jamming enemy ground to fighter R/T on 3-6 mc/s.
Mandrel	6/7.12.42	Jamming Freya.
Ground Cigar	21.22. 5.43	Ground based jamming of enemy V.H.F. fighter R/T on 38-42 mc/s.
Monica I (Aural Monica)	22. 6.43	Tail-warning device.
Grocer	26/27. 4.43	Ground based jamming of Lichtenstein BC.
Window	24/25. 7.43	Confusion of Wurzburgs and Lichtenstein BC.
Airborne Cigar(A.B.C.)	7/8.10.43	Jamming of enemy V.H.F. fighter R/T on 38-42 mc/s
Corona	22/23.10.43	Confusion of enemy H.F. broadcasts to fighters.
Fishpond	October 1943	Tail-warning.
Monica III(Visual Monica)	October 1943	Tail-warning.
Dartboard	16/17.12.43	Jamming enemy MF broadcasts to fighters.
W/T Corona (Later Drumstick)	28/29. 1.44	Jamming enemy HF W/T broadcasts to fighter.
Carpet II	24/25. 3.44	Wurzburg jammer.
Fidget	16/17. 6.44	Jamming communications passed by MF navigational beacons.
Mandrel Screen	16/17. 6.44	Jamming early warning equipment by specialist aircraft.
Jostle (HF)	4/5. 7.44	Jamming enemy HF broadcasts to fighters.
A.G.L.(T)	18/19. 7.44	Blind firing + tail-warning in rear-turret.
Type M Window	23/24. 7.44	Confusion of S.N.2. (A.I.).
Jostle (V.H.F.)	11/12. 9.44	Jamming enemy fighter broadcasts on VHF.
Dina (Later Piperack)	19/20.10.44	Jamming S.N.2.

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Methods

The countermeasures mentioned above, with the exception of Piperack and Grocer, for which little O.R.S. work other than discussion of their desirability, was carried out, are dealt with individually in the sections which follow. Methods of assessing results will emerge in each section but certain aspects of this matter, in particular the sources of information used, are common to all the countermeasures.

The object of countermeasures was primarily to reduce losses and evidence of success in this direction was always sought. Most of the countermeasures against enemy radar were expected to reduce the losses of the force as a whole and in considering these the only profitable comparison lay between losses before and after the introduction of the countermeasure. Unfortunately such comparisons were extremely difficult, in view of the many changes other than radio-countermeasures which occurred, e.g. types of bomber operating, targets attacked, tactics, conditions of weather and the state of the moon, and changes in enemy methods or equipment. Whenever possible comparisons were made in ways which eliminated some of these variables. Thus, the losses of one type of aircraft on a selected group of targets might be considered. However, results were always needed quickly in order that the need for any modifications or change in the scale of the application of the countermeasure might be perceived without delay. Therefore, it was frequently impossible to wait until sufficient sorties had been flown to provide numbers in selected samples large enough to permit statistical handling. Allowance had therefore to be made for factors other than the countermeasure by judgment and decisions taken in the light of the information available. The numbers used in the general comparison of losses were obtained from the statistics maintained by the O.R.S.

The countermeasures were expected to produce their effects by interfering with the control of specific German arms, and it was therefore possible to seek changes in the effectiveness of those arms. An index of the effectiveness of anti-aircraft fire could be provided by the extent of the damage inflicted on the bombers by flak. Fighter activity could also be gauged by the proportion of bombers reported as attacked or damaged by fighters. The statistics of damaged aircraft were obtained from the special returns made to the O.R.S. for every damaged sortie. Information on the number of fighter attacks made was derived from the reports of aircrew as made to Intelligence immediately after each operation and forwarded to Bomber Command on Form 'Z' or from the detailed 'Combat Reports' required for each occasion when a bomber either fired at or was fired on by another aircraft. In some early analyses during 1943, the number of approaches by fighters reported by aircrews were taken as a measure of fighter activity. It was found, however, by the indications of some curious results and by the observations made by O.R.S. officers at interrogation of aircrew and at the compilation of the Forms 'Z' that the reporting of these incidents was capricious. Reliance was placed therefore only on reports on incidents where the bomber or the fighter opened fire.

Comparisons using the indices of flak or fighter activity was subject to the same interference by multiple complicating factors as has been noted for those using losses as a basis. They were, however, potentially useful as indications of the particular part of the enemy's system most affected by the countermeasure under consideration and, in addition, in the case of flak damage, usually involved larger numbers of aircraft than did loss comparisons, thereby permitting more detailed analysis.

If a countermeasure was expected to affect specially the protection of the aircraft carrying it, then it was possible to assess its effect by a comparison of the records of those aircraft with others engaged with them on the same operations. This method of assessment although freed from most of the complications besetting the comparison of records of different periods of time had its own difficulties. The method was more applicable to the consideration of the effect of the devices fitted into individual bombers to warn them of hostile activity than to the assessment of the effects of direct counters to radar, and its difficulties and developments will be considered under 'Tail-Warning Devices'.

Apart from the attempts to estimate the quantitative effects of countermeasures, it was frequently possible to learn something of the effects by observations of the enemy reaction to their application. This was largely a matter for Intelligence, but sometimes the reaction could be

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deduced from the reports of aircrews and could be detected by O.R.S. methods. Thus, the position along the bombers' route at which fighter activity was experienced might be indicative of changes in the enemy system in which case the normal reports of crews would suffice, or some specific effect like the behaviour and effectiveness of searchlights might be sought by having the crews make a special report on a pro forma prepared to extract the expected information. Other effects could only be perceived by Intelligence methods, e.g. changes in frequency of enemy radar could be perceived by listening equipment, as could the reactions of the enemy fighter controllers. Such methods frequently gave the earliest qualitative information of the success of our countermeasures and were of great value.

I.F.F. Mark II, the J SWITCH and SHIVER

Exploration

Persistent reports from aircrew that the switching on of I.F.F. Mark II was followed by dousing or falling away of enemy searchlights caused considerable controversy during 1941. Was it cause and effect, and if so, what was the cause and what was the effect ? If there was genuine jamming of enemy radar it was desirable to make the most of the effect but if, as was argued by A.D.I.(Science), the enemy might deliberately encourage the switching on of I.F.F. for ends of his own, then the use of I.F.F. must be restricted. The O.R.S., in September 1941 after examining the available evidence and the several theories, found that no firm conclusion could be reached. A judicial summing up and a programme of action designed to produce evidence necessary to permit a definite decision to be reached were put forward (Bomber Command O.R.S. Report No. 10 'The Effect of I.F.F. on German Searchlights')(1).

The programme went to the root of the matter in requiring a full investigation into the mechanism of the effect and suggested special experimental flights in 'flying laboratories' manned by scientists. It was discussed at a conference held at Bomber Command on 26 September 1941. The general principles were accepted and it was agreed that 24 aircraft should be provided with a simple visual indicator designed to reveal

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whether the I.F.F. was being triggered off over enemy-held territory. One flight was made with such an indicator. The results of the flight were, as expected, inconclusive, but they showed that the indicator was probably capable of giving useful information (Report No. 16 'Effects observed by Bomber Crews using I.F.F. fitted with Visual Indicator').(1) Information about the precise effects observed by aircrews was also gathered by personal interrogation but this only confirmed the conflict of evidence.

The 'J' Switch

Before the full programme of investigating flights could be launched, the capture and examination of the Bruneval Wurzburg revealed that there was a possibility that a squittering I.F.F. could interject an interfering radiation into the I.F. stage ofthe Wurzburg receiver. Without further investigation, therefore, it was decided to make the use of squittering I.F.F. universal throughout the Command by incorporating a modification into the I.F.F. set to enable a permanent state of squittering to be produced by the closing of a switch. This modification was called the 'J' switch.

The O.R.S. prepared to investigate the effects produced by this device. A questionnaire dealing with illumination by searchlights was drawn up and sent out to all squadrons to be filled up for every operational sortie made with the 'J' Switch.

The replies to the questionnaire collected over a period of one month were analysed (Bomber Command O.R.S. Report No. 50 'The Effect of the use of the 'J' Switch of the I.F.F. on Enemy Defences').(2) The whole force was equipped with the 'J' switch, and the only possible basis of comparison was the number of illuminations by searchlights suffered by aircraft using the device only after illumination and the corresponding number for aircraft who had the switch closed continuously. It was assumed as probable that, if the switch produced any effect, beneficial or evil, such an effect would be much more pronounced for aircraft using it all the time. No difference was found between the two classes. Some

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(1) A.H.B./II/39/1.
(2) A.H.B./II/39/1.

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previous records of searchlight illumination were available from answers to a questionnaire used for a month in March/April 1942. Comparison of these with the results obtained after introduction of the 'J' switch, insofar as the nature of weather conditions and target, permitted it, also failed to show any change which could be attributed to the 'J' switch. The proportions of sorties missing, damaged by flak and attacked by fighters for each of the operations when the 'J' switch was used compared with corresponding proportions in previous comparable operations. For this purpose 'comparable' operations were operations reasonably similar in regard to geography, weather and state of the moon. Again, no evidence for an effect of the 'J' switch was obtained.

The replies to the searchlight illumination questionnaire did reveal that many crews had confidence in the 'J' switch and Report No. 50 which presented the results of the analyses referred to above, pronounced the following judgment: 'Any device which gives crews an additional sense of protection is useful provided that it has no adverse effect on other directions. Such an aid may reduce losses and should certainly tend to increase the proportion of aircraft finding the target'. As the further development of countermeasures continually provided results impossible to assess quantitatively, this pronouncement came to apply to many equipments later.

Shiver (Monkey)

While the operational trial with the 'J' switch was in progress, T.R.E. were devising a further modification to the I.F.F. set. The effect of this was to improve the power radiated in the frequency band which examination of the Bruneval Wurzburg had suggested as most worthy of attention. Report No. 50 dealing with the inconclusive results obtained with the 'J' switch, recommended operational trials with this new modification.

In discussion with the Signals Staff a plan was made for assistance to be given in assessing the effect of the new device by confining the installation to one group for an initial trial period. This was agreed, and No. 1 Group was fitted with the device which was given the code name of Monkey, later changed to Shiver 4.

There was a natural aversion to delay the full introduction of any device which was designed to reduce losses, and when the fitting of No. 1 Group was complete, installations in other groups followed. Thus, the period available for a direct comparison of 'fitted' and 'non-fitted' aircraft was very short. Had records been kept of the dates on which the various aircraft were equipped more data would have been available for analysis. As it was there were only two operations in October 1942 in which No. 1 Group alone had the device. An O.R.S. investigation was made by comparing the casualties of No. 1 Group with those of the other groups for these two operations. This comparison revealed no advantage in the use of Monkey. The intercepted night fighter R/T for the first night of operation Monkey did, however, contain four references to interference. These were not regarded by the O.R.S. as anything but a hopeful indication but they helped to precipitate the fitting of the whole force. Thereafter, no attempt at assessment of the value of Monkey, or Shiver as it then became known, by comparison of users and non-users was possible.

Use of Shiver continued until the introduction of I.F.F. Mark III became imminent. An assessment then became necessary since the retention of Shiver with Mark II involved a duplicate I.F.F. installation. Such facts as were available were marshalled and presented to the Signals staff. The bases of assessment were comparison of the incidence of flak damage before and after the introduction of Shiver, indications from Boozer(1) equipped aircraft that they were held by Wurzburgs with Shiver working and evidence from intercepted enemy night fighter control traffic. No evidence that Shiver had a protective effect could be shown and as

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(1) A device discussed on page 473.

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arguments against retention of the device it was pointed out that interference with our own Gee-H stations and with Gee had occurred and that, moreover, if any effect had been produced the enemy had had ample time to introduce effective counters and might then attempt to home on the radiation. It was suggested that experimental flights with Boozer or with special listening equipment would determine whether Shiver was completely without effect on the Wurzburgs. The arguments against continuation with Shiver were, however, accepted and these trials were not carried out.

MANDREL

Preparations for Use of Mandrel

In early considerations of the effect of countermeasures against enemy radar, the O.R.S. always placed the greatest stress on the need for jamming the Wurzburg equipment, the gear directly controlling offensive weapons. Thus, O.R.S. Report No. 4,(1) referring to countermeasures against the enemy's coastal radar chain on 250 cm, stated 'These are not considered vital to Bomber Command's night operations unless these stations are being used for "Little Screw"', the name by which the enemy G.C.I. system was then known. The problems of designing jamming transmitters proved, however, to be easier to solve for the early warning chain of Freyas than for the Wurzburgs and a device known as Mandrel came into production in 1942. This equipment was a noise jammer designed for airborne use to cover the frequency band of the Freyas. A fixed form of the equipment was also designed for operation from stations on the south coast. The design of the equipment was, of course, the responsibility of T.R.E., who also estimated the proportion of bombers which should be fitted with the device. The O.R.S. was still stressing the greater need for Wurzburg jamming, but in discussions during 1942, welcomed Mandrel as a first instalment of radio-countermeasures, particularly insofar as it might prevent the use of Freyas as putters-on for Wurzburgs. Little detailed work was, however, carried out before Mandrel became operational.

First Use of Mandrel

Mandrel was first used on 6/7 December 1942, and its effects were sought by the O.R.S. with considerable care. The largest expected effect was the reduction of the enemy's early warning of the approach of the bombers. An attempt was made, therefore, to assess the effect by comparing

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the time intervals between the bomber aircraft crossing the enemy coast and the initiation of enemy fighter activity, before and after the introduction of Mandrel. The indices of fighter activity used were the first operational night fighter R/T heard and the first reported time of sighting an enemy fighter by a bomber crew. The records of coastal monitoring stations were also examined in order to discover abnormal behaviour of Freyas which could have results from Mandrel. At the same time the losses of aircraft carrying Mandrel were compared with those of other aircraft in order that any attempt by the enemy to select the carriers for special attention should be appreciated without delay.

The results obtained were discussed with the Signals branch as they became apparent. They included some encouraging features, particularly in regard to enemy frequency changes, but during February anxiety developed about the losses of Mandrel-carrying aircraft. As was later true for many similar investigations, elucidation of the true facts was hampered by unsatisfactory and often conflicting information from the squadrons as to which aircraft used the equipment.

The comparative position in regard to losses together with the evidence for the effectiveness of Mandrel was stated in two notes passed to the Signals branch at the beginning of March 1943. The first of these, considering the results to the end of February, expressed considerable anxiety about the hazards to Mandrel aircraft in view of their comparatively high losses during the second half of February, and of a reported manifestation of hostile activity against the fighter aircraft which were forming a Mandrel screen. The second report included data for the first week of March which indicated a reassuring trend in Mandrel losses. This report, making the point that the evidence available only showed an effect of Mandrel on coastal Freyas, suggested that Mandrel should be switched off when the enemy coast was passed or alternatively that the jamming should be carried out by specialist aircraft better able to defend themselves than the operational bomber.

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The Signals branch which had been allaying the fears of the squadron about homing with well-chosen data on Mandrel losses were rightly anxious that no step should be taken which would increase such fears. Moreover, the Mandrel sets were being modified to produce a $\pm^{3}_{4}$ mc/s wobble in the carrier frequency in order to hinder direction finding on the source of jamming. It was therefore decided to await further results and the investigation continued regarding the delaying action of Mandrel on the enemy's reaction and also losses.

<u>Freya-Halbe, an Enemy Homer</u>

At the end of March the losses of Mandrel aircraft were shown to be similar to those of other aircraft but there was no evidence from the time of the first night fighters R/T traffic picked up or from the time of the first interception of a bomber that any delaying action was being produced. During May 1943 information became available that the enemy was developing a homer for use against Mandrel known as <u>Freya-Halbe</u>. The [illegible] statistics of losses maintained by O.R.S. were useful in showing that no effect of the use of such a device could be detected. Nevertheless, the threat could not be ignored and discussions on protective measures were carried on with the Signals branch and T.R.E. and with Fighter Command who carried out homing trials against Mandrel-equipped aircraft. The O.R.S. function was largely to interpret the flight trial results in relation to Bomber Command operational conditions. The final decision was that Mandrel transmissions should be interrupted so that two minutes radiation was followed by two minutes silence.

The evidence relating to the effectiveness of Mandrel, and to its effect on losses of aircraft carrying it, was summarised in July 1943. It had to be concluded that the O.R.S. methods of analysis failed to reveal an effect owing to the operation of many conflicting factors and that the only evidence of value was that provided by secret sources. It was pointed out, however, that with the imminent introduction of <u>Wurzburg</u> jamming by Window, the jamming of inland <u>Freyas</u> would become of prime importance and that steps should be taken to increase the effective application of Mandrel and to survey the frequency distribution of the inland <u>Freyas</u>.

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Close watch was kept on Mandrel losses, but apart from a brief period of excessive losses by No. 4 Group Mandrel aircraft in June 1943, no cause for anxiety appeared until the end of the year when, in No. 4 Group, losses of fitted aircraft again began to rise relative to the others. Although for No. 4 Group there were heavy odds against the difference between losses of fitted and unfitted aircraft occurring by random chance, there was no appreciable difference for other groups. Even in No. 4 Group, returning Mandrel aircraft did not report attacks by fighters more frequently than did others. An investigation was made therefore into the possibility that in No. 4 Group, the aircraft fitted with Mandrel were in some other way a special class, e.g. they were flown by inexperienced crews. No idiosyncrasy was, however, found and no adequate explanation could be offered. The results were circulated within the Command Headquarters with the suggestion that as no physical explanation could be found for the effect, Mandrel operation should be continued and if possible increased with a more extended frequency coverage. ('Losses of Mandrel-carrying aircraft, November 1943 - January 1944')[1]. Further experience showed that this advice was sound, for losses subsequently fell alike on the fitted and the unfitted aircraft, and Mandrel proved to be of great value in the re-entry to the Continent, an operation which was now beginning to pre-occupy both the planners and producers of equipment.

<u>The Mandrel Screen - Preliminary Planning</u>

It became obvious early in 1944 that any substantial increase in Mandrel coverage of the bomber force was unlikely to be possible until requirements concerned with the invasion of Europe were satisfied. The O.R.S. studies of enemy fighter tactics had long since led to the view that any delays in the enemy's perception of the direction of approach of a raiding force would reduce losses. Therefore, when the formation of a specialist Mandrel squadron with full frequency cover over the enemy's early warning chain was mooted as a possibility for use in the landings in Europe, it was pointed out that such a squadron would be of great value to the bomber force. When the creation of this squadron had been agreed

(1) O.R.S. Memo. M.162.

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and when assault preparations had also stimulated the development of a type of Window covering the Freya band, some discussion on the future of Mandrel took place with the Signals branch. It was agreed that the O.R.S. would prepare an appreciation of the situation. The result was Report No. S.148 - 'The Possible Uses of Mandrel and Freya-Window against the Enemy Early Warning Equipment'.(1) This paper made no attempt to draw on past experience, but was a theoretical treatment of the way in which Mandrel in the quantities available and Freya Window could be used to achieve screening of the approach of a bombing force, protection against G.C.I. by inland Freyas and the simulation of a bomber force by small numbers of aircraft. It was argued that:-

(a) the concentration of aircraft in the bomber stream was large enough without further aid to prevent Freya G.C.I. except on the edges of the stream, but the Mandrel should be retained in the main force until there was evidence of enemy exploitation of the radiation for plotting or homing in order to give protection to the edges of the stream.

(b) the approach of a force could best be screened by disposing the specialist Mandrel aircraft at suitable positions some 50-70 miles from the enemy coast, the positions to be chosen specially to cover the route concerned.

(c) good diversions could be produced by about 24 aircraft releasing Window.

(d) Mandrel screen and diversions which could most profitably be used together, should be employed with maximum possible variation and should be used to rouse the enemy defences on non-operational nights.

It was also suggested that the value of screening was great enough to justify forming a screen with Mandrel cover only against the long range Hoardings and Chimneys as an interim measure while full cover for the Freyas was prepared.

Mandrel Screen - Tactical Planning

On receipt of this paper the Commander-in-Chief Bomber Command ordered that detailed plans should be prepared for the operation of the Mandrel screen and Window-aided spoof forces. A map of the known

(1) A.H.B./IIH/241/22/14.

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positions of the enemy early warning radar stations was prepared, and for a large number of positions of a set of eleven jamming centres, the areas screened from enemy observation was calculated. The first process was to select a distance from the coast for the jamming aircraft to fly. This was a matter of judgment since the demands were conflicting. The closer the jammers were to the coast the more the screened area would decrease since the spacing between centres is governed by the beam width of the enemy radar. On the other hand it was felt that it was desirable for two forces to emerge from the screen headed in a way which would imply threats to well separated targets. It was evident that this could only be achieved if the screen were well away from the enemy coast. The maximum distance possible with the operation of monitoring necessary with Mandrel III was 80 miles, and this distance was selected.

Even at this distance it was decided that complete cover against the narrow beamed Hoardings was not possible if adequate breadth of cover were to be provided. Since the screen could not delay early warning sufficiently to prevent full fighter reaction against a single bomber stream flying anything but a very shallow penetration, it was considered that the aim of the screen should be maximum confusion rather than full black-out. Therefore, complete cover against the Hoardings could be sacrificed to produce increase in breadth of the area of screening.

These judgments having been reached, the whole matter was discussed at No. 100 Group and quantitative estimates of the cover provided for certain positions of the screen were made. The method used was to pin on the map of the German coastal radar paper triangles cut with their apex having the value of the beam width of the radar concerned, to place the jamming centres at about 80 miles off the coast, and to determine the positions which promised the best screened area. The expected limits of the screened area were calculated on the basis that jamming would be adequate at a signal to noise ratio of 1 to 1, and the best heights for the screen aircraft to fly at the various positions were calculated from the known characteristics of the jammers and of the enemy equipments. When the areas

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of screening were determined, the routes and timing of raids and feints through the screened area were considered in the light of knowledge of the enemy's probable reactions derived from study of fighter movements on recent operations.

The problem was complicated by the destruction of early warning sets on the invasion preparation and finally a considerable readjustment was imposed by the capture of Cherbourg. Thus, by the time the plans were fully prepared and issued within Bomber Command (Bomber Command O.R.S. Report No. B.216 'Proposals for the Tactical Use of the Mandrel Screen'),(1) the screen had already commenced operations, and the changing military situation was already affecting the enemy's reactions. The general principles developed in the report were, however, independent of particular circumstances and were useful in planning screen and diversion operations. The preparation of the report is dealt with at some length here as an example of how in an apparently largely quantitative matter, many conflicting claims had to be resolved by judgments.

Mandrel Screen - Assessment of Results

Results produced by the operation of the Mandrel Screen and of Window-aided diversions were sought by the O.R.S. both at No. 100 Group and at Bomber Command. The changing military situation and the introduction of other countermeasures spoiled any evaluation by comparison of losses or of the extent of fighter reaction for periods before and after the use of the screen. It was necessary to give individual attention to each operation and to compare the time and nature of the enemy's reaction as revealed by his W/T and R/T plots on the bomber position and orders to fighters. It was clear that, although there were frequently enemy plots of bomber positions behind the Mandrel screen, in general the expected area of confused and isolated plots was being produced. It was not possible to discover any system in the appearance of early plots.

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The Window-aided diversions also seemed to have success but also to fail occasionally without any obvious systematic cause. It did appear, however, that the Window diversions had their best successes when directed towards areas which had recently been heavily attacked and about which the enemy had been made sensitive while the real bomber force attacked a target in another area. The results were thus more or less as expected, and in writing an appreciation of the first five weeks of operations (Bomber Command O.R.S. Report No. S.172 'First Operations of the Mandrel Screen and Special Window Forces')[1] attention could only again be drawn to the deficiencies in the screen and diversions which had been referred to in the two papers on the methods of employment of the Screen (Report Nos. S.148 and B.216) and to one new development, revealed by investigating flights, an enemy early warning system on a frequency of about 36 mc/s. It was recommended that:-

(a) Carpet be fitted in the jamming aircraft to prevent plotting by coastal Wurzburgs.

(b) Measures to ensure the maximum possible restriction on radiation from the approaching bomber force should be accelerated together with the inclusion on diversionary forces of any radiator which had to operate in the bomber force.

(c) Steps should be taken to provide for jamming of the suspected enemy 36 mc/s early warning set.

(d) Trials of a Window diversionary force should be made against captured enemy equipment.

(e) The investigating flights of No. 192 Squadron should be supplemented by use of Bagful[2] in the bomber force.

With the exception of (e) all these redommendations were carried into effect, although (d) had to wait until March 1945 for its fulfilment. The recommendations put on paper in orderly fashion were already common thought at No. 100 Group, and in the Signals branch at Bomber Command, but as in other cases their issue in official form with a reasoned backing no doubt helped to produce action.

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(1) A.H.B./II/69/284.

(2) A device for recording enemy frequencies.

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Investigation into the effectiveness of screen and diversions continued without revealing any new enemy means of defeating their object. It became suspected towards the end of 1944 that the enemy's broadcast plots and directions did not begin when he obtained his first plots but were timed so as to sustain for British benefit an illusion that the screen was delaying his action somewhat longer than was in fact the case. There could be little check on this. An attempt was made by comparing the times of first plots with the times of switching off enemy broadcast transmitters, with inconclusive results. Examination of the data concerning the occasions when enemy fighter movements appeared to precede plots of the bombers' position suggested that no more than the intelligent anticipation of the direction of attack had been made, based either possibly on the position of the Mandrel aircraft or on intruder activities.

Unfortunately for the purposes of investigation the few occasions when Mandrel was not used were marked by some other peculiarity and gave no real clue to the enemy's state.

The efficiency of the Mandrel screen came into question after the military advance to the Rhine, and a final appraisal of its value was made in a minute to the Air Staff on 3 April 1945. This summarised the investigation of operations for the months of February and March. In effect the result was that obtained throughout the period of the operation of screen and spoofs, namely that sometimes they worked and sometimes they did not as was to be expected from their known deficiencies. It was pointed out that the enemy had begun to associate the appearance of the screen with an operational threat and that low level approaches without a screen would probably achieve a surprise. Heavy bombing became unnecessary before further developments could be pursued.

The end of Main Force Mandrel

The withdrawal of Mandrel from the bombing force is worthy of comment. In early May 1944 suspicion grew that the enemy was operating an A.I. equipment in a frequency of 160-170 mc/s. Methods of countering this were discussed with the Signals branch, and it was concluded that Window could be

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supplemented by modification of Mandrel sets to cover the required task. The conclusion reached in Report No. S.148 that the concentration of the bomber force was high enough to defeat Freya G.C.I. was accepted as permitting withdrawal of Mandrel from its original duty of jamming the most populous Freya band. T.R.E. reacted against the proposal pointing out that the jamming of the A.I. by modified Mandrels would be inefficient and that modification of I.F.F. Mark II would be a better proposition. The question was discussed at length by the Signals branch, T.R.E. and O.R.S. O.R.S., while agreeing with the quantitative arguments of the T.R.E. view, supported the Service thesis that to be able to do something immediately was to be preferred to something better after a delay which, as experienced with other equipment had shown, might be very many months. There could be no quantitative justification for the argument. It might have been that Mandrel jamming would have left the A.I. with enough range to give the operators as many contacts as they could deal with. Once again the basis of action was judgment, this time derived from a belief that anything which would give additional worry to the fighter crews, already harassed by communications jammed, was worth trying. The principle of converting Mandrel was accepted but no firmer news of the 160-170 mc/s A.I. came in, and when the S.N.2 (90 mc/s) became known Mandrel was finally withdrawn from the main force (28 July 1944). The use of long Window and the desire to restrict radiation from the main force made its re-introduction unnecessary and undesirable.

WINDOW

Initial Considerations

The idea of releasing conducting bodies from aircraft in order to confuse radar observations had been in mind since the early days of the development of the military application of radar. It became an early interest to the O.R.S. at Bomber Command, and on 5 September 1941 in a memorandum to D.C.D. experiments on the subject were asked for without delay. In this memorandum it was pointed out that the enemy radar used for searchlights and flak was working on a wavelength of 53 cm and might therefore be countered if each aircraft carried a number of bundles of dipoles of length 26 cm cut from aluminium foil to be thrown out when near ground defences.

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After many months of discussion and following trials conducted by T.R.E., Window, the code name allotted to the operation of releasing conducting bodies to deceive radars, became an operational possibility in April 1942. A draft instruction for the use of the countermeasure was prepared by the Air Staff and circulated to the Signals branch and to O.R.S. for comment. The Window material then available was in the form of metal foil propaganda leaflets of size $8\frac{1}{2}$ inches x $5\frac{1}{2}$ inches and a bundle sufficiently large to produce an aircraft echo on the enemy's Würzburg had been estimated by T.R.E. at $4\frac{1}{2}$ pounds. Thus the number of bundles which an aircraft could carry was severely restricted, and moreover, the amount of material available was small. The advice given, therefore, was to ensure that best possible use was made of the amount carried by defining areas of use and rates of release. It was suggested that the main effort should be made at the target, the only place where the concentration of aircraft could be expected to be sufficiently great to give results with small quantities of Window. The rates of release required to produce the concentration of Window of 10 echoes per square mile recommended by T.R.E. were worked out, and it was suggested that the first 20 aircraft over the target release one bundle every half-minute over the target, and the remainder one bundle per minute for periods of eight minutes in each case. It was also suggested that aircraft threatened by searchlights on route should release four bundles at half-minute intervals and orbit.

The operational use of Window was banned before such instructions could be put into practice due to fears of retaliation by the enemy, but the approach which had been made towards operational use stimulated great interest in the development of the best methods of use.

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Wurzburgs as well as that of the Freyas, Hoardings and Chimneys. The point was also made that any electrical jamming would readily be perceived by the enemy radar, and that therefore Mandrel and Carpet (the Wurzburg jammer) should be carried in the feint forces covering the same frequency ranges as the similar equipment in the main force.

Window Feints - The Operational Use

When No. 100 Group began to operate the Mandrel screen and Window feints, the principles laid down in the O.R.S. reports were followed. In the course of the preparation of the second report (No. B.216) discussions were in fact carried on with No. 100 Group. The number of aircraft available for feint forces was, however, always below the number of 25 which had been suggested as necessary, and an attempt was made to compensate for this by increased rates of Window release.

The success of Window feints could only be judged by the enemy's reaction to them as obtained from intercepted fighter control communications. This source of information was carefully watched, and after six weeks use of the feints a joint appreciation was prepared by O.R.S. No. 100 Group and O.R.S. Bomber Command. The apparent success of the feints was considered in conjunction with the variations in application, e.g. number of aircraft taking part, area of operation etc. The results (Report No. S.172 'First Operations of the Mandrel screen and Special Window Forces')[(1)] were inconclusive. It appeared that the feints were most successful when aimed at an area which the main force had been attacking in the immediate past at the time when the attack was switched to another area. Otherwise there was no apparent systematic cause of success or failure. Recommendations for improvement had therefore to be based on the deficiencies suspected from first principles. They were to increase the number of aircraft taking part and to include in the feint force aircraft equipped with all the radiating devices carried in the main force. It was also recommended that trials of a Window force against captured enemy equipment should be carried out. As aircraft and equipment became available, these recommendations, which put into writing what had probably been in many minds, were acted on although it was not until March 1945 that a trial against a captured enemy Freya was carried out.

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(1) A.H.B./II/69/284.

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The evidence for the success of Window feints was kept under review but no definitely systematic variation was revealed. There were, of course, many factors, such as the navigational accuracy of the Window forces, which could not be taken into account. A final appreciation was presented at a meeting of the Operational Research Committee on 'Tactical Aids to the Defence of Bombers against Night Fighters and A.A. Fire' on 16 March 1943 (Report on Bomber Command Tactics attached as Appendix to the Minutes of the Meeting).(1) The conclusion was that the Window feints had had many successes but sometimes appeared to be correctly appreciated by the enemy, and that the best chance of success was obtained when the Window force broke away from the main force after flying with it until within range of the enemy radar.

Liaison and Propaganda Work

In spite of the long period of development, Window made a rather sudden impact on the Command organisation when it was introduced. This was largely because of security measures in force before the introduction of the countermeasure, but the effects of the impact was enhanced by the fact that there were no precedents for the control of a measure such as Window. As a radio countermeasure Window was clearly a sphere of influence of the Signals branch but the technical problems involved were remote from those to which that branch was accustomed. The discharge of material from an aircraft was akin to practices of the Armament branch but the material itself was quite unlike the material handled by that branch. After a brief experience, the Armament branch at Bomber Command handed over responsibility for Window launching to the Engineer branch. The use of Window called for special tactical planning which of course involved the Air Staff. Finally, a large volume of expendable material had to be handled and thereby imposed on the Equipment branch in a large new burden.

Thus many branches were concerned with different aspects of Window, and the O.R.S. concerned with all the aspects drifted into the position of a central information exchange. This position became recognised officially when the Command representation on the Window Panel was delegated to O.R.S. This panel was formed under the chairman ship of Wing Commander D.A.Jackson (T.R.E.) to investigate means of stimulating production and of improving

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the efficiency of Window, and to consider the development of new types. Its work will be discussed later.

One important duty which fell to O.R.S. was the keeping of a record of the Window stock. During the first few months of the use of Window the threat of exhaustion of supplies was always very real. Therefore, every morning the consumption of the previous night's operation was estimated by measuring the track mileage flown within the Window release area and doing the necessary arithmetic. The production during the day was estimated as one-seventh of the previous week's total production and from this figure and the night's consumption the nett change in the stocks was derived. The stock figure was checked weekly by returns from units holding stocks, and there were many anxious occasions when investigation into discrepancies was necessary. The rendering of stock figures long survived any need for it, and the Air Staff only consented to the cessation of the daily rite in May 1944 when more than ten million bundles of Window were held. It may be mentioned that the unit Window quantity most employed originally was the ton. This unit became meaningless when more than one type of Window became available, but so attached had the many interested parties become to the measure that it became customary to express quantities in 'equivalent tons' - the weight which the Window would have if it were all made in the form of the original type. This remarkable unit unfortunately gave the impression to many that Window was a mystery to which only scientists could have the key.

The Window Panel

It was mentioned earlier that the Command representation on the panel responsible for the development of Window material was made through the O.R.S. Since the work of this panel contributed very extensively to the success of Window a further reference to it is desirable. At the time when the panel was constituted (September 1943), initial stocks of Window were being exhausted and shortages of aluminium foil, paper, machines and labour were menacing production. Moreover, the launching of the existing type of bundle from aircraft was beset by troubles which concerned both the make-up of the bundles and packages and the arrangements within the aircraft. A considerable programme of exploration of

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new sources of supply was therefore necessary, and the panel acted as the necessary co-ordinating authority. Initial meetings were held weekly, later less frequently, but until the end of the European war the frequency of meetings of the panel was never less than monthly. The panel reported periodically to full assemblies at Air Ministry of all the parties interested in the production and use of Window. These were usually attended by Service representatives from Bomber Command in addition to the O.R.S. Decisions of the panel were, however, normally put directly into practice and only policy changes awaited confirmation by the full assembly.

The technical aspects of Window development were, of course, the concern of the appropriate M.A.P. branches, and the testing of products and of launching chutes was conducted by T.R.E. and B.D.U. Bomber Command's principal concern on the panel was to ensure that the required frequency coverages should be provided, that methods of packing and the weight and bulk of material should be such as to minimise difficulties of discharge, and above all that the required quantities should be forthcoming. Samples of paper, of boxes of strips, and of forms of packing were examined in large numbers and considered in relation to information gathered from aircrews about operational difficulties. Later, when methods of packing had been almost standardised, the need to meet quickly the changing demands for new forms of Window became the most pressing problem. This became acute when the threat of enemy centimetric equipment emerged. At this stage another small planning group was formed as a sub-committee of the Radio Countermeasures Board of Air Ministry. The aim of this sub-committee was to examine possibilities of making fundamental changes in the Window operation in order to meet the centimetric threat. Command representation on it was through O.R.S. Plans were formulated and the appropriate bodies delegated to develop the projects. This development was still in progress at the close of the European war.

Launching from aircraft was also a concern of the panel, and in January 1943 the principles of what was later built as the Fairey automatic launcher were evolved in discussion.

It is, of course, impossible to assess individual contributions to a body such as the Window panel which depended on discussion and the pooling of ideas. The achievement of the body as a whole was, however, noteworthy, and is reflected by the great progress made. In extremely difficult circumstances Window production was built up to a sufficiently high level to meet any likely demand, and at the same time was sufficiently flexible to meet rapid changes in demand. The form of Window insofar as it affected security of packing and ease of launching was improved enormously. In addition, considerable economies in the use of metal foil and paper were effected - the weight of aluminium in 1,000 bundles of anti-Wurzburg Window was reduced from 600 lbs to 51 lbs and the weight of paper from 1,100 lbs to 220 lbs.

Propaganda Work for Window

The need for propaganda in the Window factories in 1943 and how it was met by quoting the saving in aircraft and crews has been referred to previously. Propaganda amongst the users and amongst the controllers of supply of materials also became necessary. As the aircrews who had seen the first effects of Window finished their operational tour, they were replaced by others who carried out Window dropping as a routine, without understanding its purpose. Inevitably, such a routine was neglected by some, and when scraps of information from the squadrons revealed a rather widespread ignorance a short account of the way in which Window produces its effect, the need for care in launching and an outline of its influence on the enemy defensive system was prepared for the Air Staff as a simple guide for the instruction of aircrew in Report No. B.209 'Some facts about Window' April 1944.(1) This report was sent by the Air Staff to groups with a suggestion that suitable extracts should be made and distributed down to squadron and flight commanders. Although it served a useful purpose by spreading correct information, the process did not go far enough. Therefore, after the introduction of long Window, a revised simplified and shortened /version

(1) A.H.B./IIH/241/22/12,

version was prepared as 'More about Window' in August 1944. This included a simple diagram of the appearance of Window on a radar presentation with indications of the failures likely to arise from a faulty use of Window, sufficient in itself to explain the use of Window to the impatient reader. This report was circulated as a whole down to squadrons by the Air Staff.

The many types of Window which had come into use by the summer of 1944 were also causing confusion at all levels of the Service branches concerned. In an endeavour to clear this, a catalogue of Window was prepared, listing the many types with an indication of the make-up of these bundles, and their purpose, together with an introduction summarising the reasons for the multiplication of the number of types. These documents were issued as Report No.B.220 'Types of Window'.(1)

At the beginning of 1945, the apparent approach of the end of the war caused some of those responsible for the provision of materials to look to a reduction in Window production as a possible immediate economy. One of the results of this was a proposal to remove Window from the list of 'designated' products, the effect of which would have been to lose some necessary priorities including that of labour. The O.R.S. was asked for information on the value of Window to combat this proposal. Examples were given of the successful use of Window in its four functions; interference with radar-controlled flak and searchlights, interference with G.C.I. carried out with Wurzburg, Freya or Jagdschloss, interference with A.I. and the production of spoof attacks. It was possible to point to the continuously lower flak damage rate since Window was used, to the total escape of the force on some nights when a G.C.I. system would have exacted a considerable toll, to the success of Type M against S.N.2 and to examples of successful Window feints. The proposals to regard Window as no longer fully essential were defeated.

The Launching of Window From Aircraft

Hand-launching

The problems of packing and wrapping for Window bundles have already been mentioned. The provision of facilities for the hand-launching within the aircraft was essentially an engineering problem, but it was one in which

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(1) A.H.B./IIH/241/22/12.

O.R.S. had to take a general interest since the outlet used was from the beginning tied up with the form of the Window bundle and later determined the type of Window which could be used. Therefore, from October 1942 onwards participation in discussions and observation of trials concerning launching were carried on for about a year when the B.D.U. completed the design of a cowled chute which would permit satisfactory launching of all types of Window. Thereafter, apart from special consideration for aircraft taking part in Window feints in the Overlord operation, the main concern of the O.R.S. with hand-launching was to advise on the distribution of types of Window in order to ensure that aircraft used only the types for which their chute was suitable.

Automatic Window Launching - Development

It was always intended that hand-launching should be replaced quickly by automatic launching and long before the use of Window became an immediate prospectand even before the rates of discharge and the size of bundle had been decided the requirements for an automatic launcher were considered. The several possibilities of launching rates were given to the Air Staff, and it was suggested that the requirement for an automatic launcher should embrace all of them. The capabilities required on this basis were stated as a rate of launching variable between one and 30 pounds per minute and a capacity without reloading of 100 pounds. The design of automatic launchers had made little progress by the time the operational use of Window began. Then a period of intensive exploration revealed many technical difficulties. The O.R.S. acting as a liaison section in this as in other Window commitments, maintained contact with the various parties concerned in order to keep alive a sense of urgency and to ensure that the requirements of the Command were met. These requirements had been re-stated in accordance with the more definite estimates of the rates of release and total amount of Window prepared after the operational introduction of the countermeasures as:-

Capacity	1,000 bundles
Release Rate	Variable from one bundle in two minutes to six bundles per minute; the rate to be capable of selection in the air.
Size of Bundle	Up to 45 cm long and 7 cm diameter.

Several designs of launchers were examined and one of them reached the stage of extensive trials by B.D.U. at the end of 1943. The results of these trials were discussed at a meeting of the Window Panel on 5 January 1944. It was decided that the faults of the machine made it unacceptable, but in the discussion the basis of design for a new type of launcher was evolved. The B.D.U. set to work on this basis and rapidly developed the design, the O.R.S. representative at the unit giving considerable assistance. Within three weeks a stage had been reached when the co-operation of the Fairey Aviation Company could be called for in order to bring the machine on to a possible production basis.

The period of development which followed was long and troublesome. The newly formed Operational Requirements branch at Bomber Command took over the responsibility of urging on the development and the role of the O.R.S. became one of advising what adjustments to the Command's original requirement could be accepted. These involved mainly the total capacity of the launcher and release rates for newer types of Window. In general, reductions on the original specification were advised in order that production should not be delayed, but no compromise on the maximum rate of launching of the Wurzburg/Lichtenstein Window was considered acceptable. In fact, when it appeared possible that a supply of launchers might be supplied from American sources it was recommended that a rate of launching of ten bundles per minute should be possible 'in order to be prepared ...... for a measure of deconcentration'.

By November 1944, there appeared good prospects that automatic launchers would be available for operational use in the course of a month. The immediate result was to provoke a mild flurry within the Command since the setting up of a special organisation on each operational station had to be envisaged. The problems were discussed at a meeting at Headquarters Bomber Command called by the Air Officer Administration on 11 November 1944 at which it was necessary for O.R.S. to urge once again that Window was an operational necessity and that its most efficient use demanded automatic launching. This meeting decided that an operational trial should be carried out in order to decide the magnitude of the organisational problems involved.

The production of operationally suitable models of the launcher was, however, further delayed, and in January 1945 it seemed that the introduction would be preceded by two other introductions which had a strong

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bearing on the usefulness of the machine. These were the provision of the Glenn-Martin mid-upper turret in the bombers and the development of a centimetric A.I. by the enemy. The considerable obstruction in the fuselage brought about by the turret would have made the bulk of the magazines of the launcher extremely undesirable and the rates of release required to counter a centimetric A.I. were far beyond the capabilities of the existing machine. The position had therefore to be reviewed and at a meeting at Air Ministry held on 25 January, the Command representatives intimated that the Fairey launcher could no longer meet the Command's requirements.

Air Ministry requested a new appreciation of the Command's requirements. A note was therefore prepared by the O.R.S. after consultation with the Air Staff and Signal branch. This note summarised the probable future requirements for Window launching in the European and Far Eastern theatres, and pointed out how the existing design of automatic launcher would fail to meet them. It was proposed that the operational trial with the existing design should proceed in order to obtain information useful in future design, but that development of types better able to meet requirements should be pursued with vigour. The note 'Automatic Window Launchers for Bomber Command' over the signature of the Chief Signals Officer, was circulated before a meeting at Air Ministry on 2 February. At this meeting it was agreed that new designs, including those of semi-automatic types and of externally carried machines, should proceed. The Command was asked to submit revised requirements. After a general outline had been sent to Air Ministry by the Operational Requirements branch, a more detailed statement clarifying the Command's position was drafted by the O.R.S. and was forwarded by the Operational Requirements branch. This statement urged the development of a hopper type of launcher to be re-loaded occasionally in flight. It was considered that such a design offered the best means of making possible high rates of discharge without the need of storing the large bulk of Window required in one fixed mass.

Automatic Launchers - Operational Trials

When there appeared to be a good prospect of being able to carry out the projected operational trial with the Fairey Launcher, a note was

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prepared setting out what were considered to be the objects of the trial, how they should be attained and the preparatory action needed to organize the trial. This note ('Memorandum on the projected trials of the Fairey Mark I Automatic Window Launcher at Little Staughton') was discussed at a meeting of representatives of the Air Staff, Signals, Operational Requirements and the O.R.S., and formed the basis for the organization of the trials. The squadron selected for the trial was No. 582 of the Pathfinder Force, at Little Staughton. The squadron was visited by representatives of the Air Staff, and the O.R.S. and arrangements for the trial were completed. These included the stationing of an O.R.S. representative at the squadron for most of the duration of the trial.

Installations of the launchers commenced during March 1945 and an O.R.S. representative paid visits to the squadron to observe the difficulties experienced and to advise on procedure. When the organisation had settled down the representative stayed at the squadron and it was also arranged that a party from the Air Ministry Manpower Research Unit should attend in order to record the time and labour consumed in servicing the launchers. The O.R.S. officer supervised the work of this party, inspected launchers after operations, discussed its performance with the aircrews and maintained appropriate records.

The results of the trial were presented in Bomber Command O.R.S. Report No. 134 'The Operational Trial of the Fairey Mark I Automatic Window Launcher'.[1] They included an analysis of the recordings made by the Manpower Research Party which established the labour needs for servicing the launcher, an estimate of the transport required, detailed analysis of the numerous failures which occurred and comments on the crews' reactions. Altogether the results provided a depressing picture and formed in fact a final condemnation of an already discredited type of launcher.

CARPET

The need for a jammer for the enemy's <u>Wurzburg</u> apparatus used for control of flak and fighters was recognised as of the highest degree of urgency from the time of first knowledge of the enemy equipment. The

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(1) A.H.B./II/69/175(D).

technical difficulties were, however, considerable and it was not until the end of 1943 that T.R.E. was able to offer in Carpet II a jammer suitable for use in the British bomber force.

Carpet II included a search receiver which could sweep a band of frequencies 50 mc/s in width pre-selected from the range 450-600 mc/s. When an incident pulse was received on a frequency within the band being searched, the jammer tuned on to it and jammed it for a time which could be pre-set for any period between a few seconds and five minutes. The time for a complete searching sweep was one and a half seconds.

By the time that the device was at a stage when quantity production could be contemplated, Window was being used with success to counter the Wurzburgs and consideration had therefore to be given to the decision whether or not the addition of the electrical jammer would be worthwhile. An O.R.S. appreciation of the position was prepared at the request of the Signals branch (Report No. S.119 - 'The Possible Uses of Carpet II in Bomber Command').(1) The effects of Carpet with and without the additional use of Window on G.L. and G.C.I. operation were considered together with the probable enemy reactions. The scale of fitting with Carpet to produce the best results was also estimated. Technical data supplied by T.R.E. was available concerning the expected effect of a Carpet on one Wurzburg, but the effect of mutual support of both bombers and Wurzburgs had to be estimated using assumptions of their distribution in space.

Although Carpet had certain advantages over Window in regard to weight and bulk and the manipulation required, it was considered to have less flexibility in regard to volumes of production. It was suggested, therefore, that the two countermeasures should be regarded for the time being as complementary. Carpet appeared well suited to provide cover in circumstances where Window was least effective, e.g. at the head and fringes of the bomber stream and in operations by small forces. Taking the long-term view, however there seemed to be a possibility that the concentrated raids necessary for the use of Window might become tactically disadvantageous and the greater tactical freedom which would be provided by the complete equipment of the

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(1) A.H.B./IIH/241/22/14.

force with Carpet would then be most valuable. The recommendations made were therefore that provision should be made for equipping the whole heavy bomber force with Carpet, priority being given to the Pathfinder Force and and specialist radio countermeasure aircraft who were most likely to have to fly in zones of reduced Window cover. The Command policy was stated to Air Ministry on this basis.

Introduction into Operations

Sufficient equipment was available by March 1944 to begin fitting the Pathfinder Force. The method of employment was discussed with the Signals branch. The period of jamming which each set should hold before resuming search for new frequencies had been recommended as two minutes in Report No. S.119 mentioned above. This period seemed a reasonable compromise between the prevention of ordinary radar plotting and the denial to the enemy of a useful D/F on the source of jamming. It was accepted for operational use, with the proviso that it should be reviewed later in the light of experience.

The Wurzburg frequencies were known to be spread over a band 100 mc/s wide, whereas each Carpet set could only search a band of 50 mc/s. Since initially there appeared to be too few sets available to provide mutual support, each set had to be used to cover as many Wurzburgs as possible. Therefore, it was decided that each set should search the same frequency band. This was selected as 530-580 mc/s which, according to Intelligence information, would include the greatest number of Wurzburgs.

The Carpet sets were fitted with an indicator light to show when the set was jamming and crews were requested to log the times and duration of periods of jamming in order that the need for any change in the jamming period or the frequency search band might be perceived.

The first reports made by crews showed that many sets were jamming almost continuously. This was rather more than had been expected from what was known of the distribution of Wurzburgs and an O.R.S. officer visited the squadron concerned to interrogate the crews. There appeared to be no doubt that the reports were justified and a probable explanation was considered to be ~~that the reports were justified and a probable explanation was~~

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~~explanation was considered to be~~ that the receivers of the sets were too sensitive and that the jamming was therefore being applied to Wurzburgs too distant to obtain useful radar plots. A check of the sensitivity confirmed this and after discussion with T.R.E. a maximum sensitivity for the setting of the receiver was agreed on. This change produced results more in accordance with expectation, although the non-jamming periods remained few and short. Another modification introduced as a result of T.R.E. tests was a reduction of the width of band searched to 40 mc/s, 540-580 mc/s being chosen.

Statistics of the casualties to Carpet carrying aircraft were collected and after ten weeks operational experience a survey of the results was made (Report No. B.215 'A Note on Initial Operational Experience with Carpet II')[(1)]. The numbers of missing aircraft were rather too small to permit a satisfactory assessment to be made. Numbers of aircraft damaged by flak were somewhat larger, and since, in view of the decline in enemy G.C.I., the use of Carpet was expected to produce its most marked effect on gunfire control, these numbers provided a reasonable basis for consideration.

It appeared that the use of Carpet had been associated with an appreciably lower risk of flak damage, an impression which was confirmed when the categorised severity of the damage done was considered. Thus, there was some indication that Carpet could provide some protection for aircraft carrying it. An attempt was made to assess the general effects of the device on the parts of the bomber stream in which it was carried. Two thirds of the Carpet using sorties had been briefed to bomb in the early stages of a raid. A comparison was made therefore between the losses of main force aircraft planned to fly in the front of the bomber stream and those planned to fly at other parts. None of these aircraft was carrying Carpet. It was shown that since the introduction of Carpet, losses for all parts of the stream except that in which the jammers were concentrated had risen.

Interpretation of this result was complicated by variations in the enemy fighter tactics which had considerable influence on the relative losses of

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(1) A.H.B./IIH/241/22/12

different parts of the bomber stream and it could only be regarded as promising. Thus, although the limited amount of evidence accumulated in ten weeks experience could not permit a final assessment of the value of Carpet to be made, it all tended to give a favourable impression of the device. As with most of the other radio-countermeausre devices, action on production could not wait for statistically significant results; judgement had to be made on the impression gained and the recommendation was made that the fitting of Carpet should be extended throughout the force. The argument that such fitting would permit greater tactical freedom in handling the bomber force was regarded as strengthened by the promising results. The recommendation was accepted and the Air Ministry was asked to endeavour to arrange for the whole bomber force to be fitted with one set per aircraft by the winter of 1944-45, and to make provision for two sets per aircraft as soon as possible in order to give greater frequency coverage.

Later Operational Results

The promise of the early results was not fulfilled by subsequent experience. As the scale of fitting and the numbers involved in comparative assessments increased, it became more difficult to discover that Carpet was producing any effect on the casualties of aircraft carrying it. Trials with captured equipment had shown that the performance of Carpet could be improved. There was some tendency for the sets to lock off frequency when activated by a strong signal, and also the aerial used with the set was not to the design best able to produce a maximum jamming signal through the Wurzburg aerial which could be made selective as to plane of polarisation. The indecisive results obtained with Carpet were marshalled and put forward to the Signals branch as an incentive to urge the technical improvement of Carpet ('Carpet II; Statistics of Losses and Flak Damage' O.R.S. internal Memorandum No. M159) (1) As a result, Air Ministry was requested to arrange for the modifications necessary for the improvement in Carpet with a minimum of delay. The modification designed to improve the accuracy of locking to frequency was carried out in the course of the next few months, but fitting of the most suitable form of aerial was never accomplished.

/Fitting

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Fitting was extended to include in addition to the Pathfinder Force, some squadrons of Nos. 3 and 5 Groups which were frequently obliged to fly at the head of a bomber stream. The operational statistics for each of the three Groups were examined in great detail, but no consistent effect of Carpet could be perceived. The enemy Wurzburg band was extending, no doubt as a result of jamming and the 140 mc/s band to which the Carpet search was confined was no more densely populated by Wurzburg frequencies than at least one more band of equal width. Moreover, the aircraft not protected by Carpet had Window cover against the Wurzburgs. It was not expected, therefore, that a very appreciable benefit from Carpet would be perceived. The U.S.A.A.F. was also using Carpet in a form suited to the protection of its bomber forces and discussions on the results obtained were carried on from time to time with the O.R.S. of the Eighth Air Force. The American results were also rather inconclusive but it appeared likely that some effect was produced when the jamming of the whole Wurzburg frequency band was made more complete. There was evidence from captured documents and equipment, interrogation of Prisoners of War and other Intelligence sources that the enemy was expending effort on measures to combat jamming.

The use of Carpet II was therefore continued and fitting was extended. Arrangements were made to spread the jamming over an 80 mc/s band and, as a check on the relative needs of the two 40 mc/s bands chosen and on the general performance of Carpet, counters were, at the suggestion of T.R.E., fitted to some of the sets. These counted the number of times which the sets stopped searching and jammed during an operation. The results obtained with the counters were analysed as they became available. It was soon apparent that some of the counts obtained were larger than could be produced by two minute jamming periods without searching periods through the whole operation. It was thus possible to indicate from the counts that the setting up of some of the jammers was probably incorrect. The approximate equality in the jamming effort expended on the two 40 mc/s search bands could also be demonstrated. The use of counters was therefore considered to be worthy of extension. It was hoped by use of them and by experimental changes in the sensitivity setting of the Carpets to determine the best

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~~sensitivity setting of the Carpets to determine the best~~ setting as the high number of jamming periods counted on an operation indicated that the sets might still be activated by Wurzburg at too great a distance. More counters were provided, but the end of the European war came before they could be used with profit.

A final review of the results obtained with Carpet failed to reveal that the device had been beneficial to the aircraft which had carried it. Thus the use of another device had been carried out and extended on judgement only without statistical evidence of success. This was fully justified since, owing to the incomplete cover of Wurzburg frequencies by Carpet, the simultaneous use of Window and the general deterioration of the enemy defences during its period of use, an effect large enough to be revealed by the usual numerical comparisons was not to be expected. On the other hand, the accepted need to be prepared for operations with forces less concentrated than were suitable for the use of Window and the knowledge that the enemy was being obliged to spend effort on trying to avoid jamming at a time when his resources were contracting made the countermeasure of Carpet desirable so long as no adverse effect of the risks of aircraft carrying it could be perceived.

SIGNALS SILENCE

Preliminary Considerations

In January 1944, Intelligence had established that the enemy was activating I.F.F. sets left switched on in bomber aircraft and was using the resulting transmissions to obtain early warning of the approach of a raid and to plot its course. This was relatively easy to check by ensuring as far as possible that no I.F.F. sets were switched on. By June, however, it had become known that the enemy was also obtaining information about bomber movements by plotting the source of other radiation including that from the R.C.M. equipment, tail-warning devices and the navigational aid **H2S.** There was also a suspicion that enemy fighters were being equipped with devices which permitted them to home on to bomber's transmissions. Radiation from bombers could not of course be stopped without loss of the

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benefits conferred by use of the radiating devices, and this loss had to be weighed against the probable saving likely to result from denial of their use to the enemy plotting system.

This was not a matter in which quantitative balances could be struck and much discussion resulted within the Command and with T.R.E. on the probable performance of the enemy listening equipment. There was one rather doubtful piece of evidence from analysis of operational data. In one operation which involved two targets, the two forces differed considerably in the proportion of aircraft using H2S. The force making most use of this device was much more heavily engaged by enemy fighters than was the other, and it was considered that the fighter controller might have assessed the relative importance of the two raids on the basis of the radiation picked up (Report No. B.213 'Report on Losses in Night Operations 21/22 June 1944, Wesseling - Scholven').(1)

The general problem was fully discussed at a meeting of the Operational Research Committee on Tactical Countermeasures to Enemy Night Fighters and A.A. defences on 11 July, 1944. The primary purpose of this meeting was to consider measures which would assist the protection of thebomber force during the winter 1944/45. T.R.E. put forward suggestions that the bomber force should no longer be flown to the target in a compact stream but should be used in a much reduced concentration in space, reliance being placed in electrical jamming to counter the enemy's Wurzburgs and A.I. ('Aids to the Bomber Offensive during the winter 1944/45, Part I, Bomber Losses' 23.June1944 - paper submitted by Chief Superintendent T.R.E. to the O.R.C. Sub-Committee.) The Bomber Command O.R.S. view was that the possibility of fighters homing to bomber radiations could defeat such a scheme. The jammers carried for the bombers' protection would themselves become homing beacons, and it appeared very doubtful if jamming of the enemy A.I. would be sufficiently effective to prevent its use for completing an interception initiated by homing. Air Staff represented that H2S was an essential aid to navigation and since if this device were used there was little point in ceasing the use of other radiating devices, the Sub-Committees conclusion was that the

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Command should be prepared to vary its tactics as much as possible, careful watch being kept on the losses of aircraft carrying radiating equipment.

The First Firm Recommendations

Almost immediately afterwards anxiety was increased by the sure confirmation that the enemy had equipped a proportion of his fighters with devices which would permit them to home on to transmissions from the tail-warning device Monica or from the navigational aid H2S. An appreciation of the dangers of the enemy development and of the possible countermeasures was prepared jointly by the Signals branch and O.R.S. for the guidance of the Air Staff (Report No. B.218 'An Appreciation of the Use by the Enemy of Transmissions from our Bombers').(1)

It was clear that there were four ways in which the enemy might profit by his receivers; gaining early warning by ground listening, plotting the course of the bomber stream by ground listening, homing fighters into the bomber stream by use of airborne receivers, and homing on to individual bombers by use of airborne receivers.

Of these threats only the last one, homing on to individual aircraft, could be assessed by reference to operational statistics. It was possible to show that aircraft using Monica or H2S had loss-rates similar to those of otherwise comparable aircraft without the devices. For Monica this might mean that the benefits from use as a tail-warning were being cancelled by the disadvantages of being homed on and the need for seeking safeguarding measures was emphasised.

In order to deny the enemy early warning from transmissions, it was clearly necessary to stop all radiation until the force was within expected range of the enemy's normal radar system. Since H2S serviceability was likely to be adversely affected if switching on was delayed until the aircraft were at operational height, it was considered that immediate orders to delay transmission were inadvisable, but that the modification of the H2S sets necessary to permit switching on at any time should be regarded as urgent.

Enemy plotting of the bomber force over territory in his occupation was possible by means of his own radar and his Observer Corps. Therefore,

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although additional aid was given to him by bombers' transmissions it was considered that such aid should not outweigh the advantages to the bomber force resulting from the use of radiating devices.

The possibility of fighters homing onto the bomber stream was, however, regarded as a much more serious menace. Communications between the fighters and their ground control had always been regarded as a link in the enemy defence chain most vulnerable to countermeasures, and the use of homers threatened to make such communication almost unnecessary. It was recommended that should the use of Monica continue to give results which suggested that the risk of homing onto individual aircraft could be tolerated, the using aircraft should be employed as a separate force in order that unfitted aircraft should be spared the attention of fighters homing onto the stream.

Some use of H2S, e.g. in target marking and for intermittent checks on navigation, was considered to be essential but it was suggested that trials should be carried out to ascertain how far the use could be restricted, and that the development of an additional aid, Loran, should be accelerated. A recommendation was also made that in order to assist in assessing the homing danger, the aircraft using H2S should occasionally be sent to the target on a route separate from that of aircraft not using the device.

Finally, since it was envisaged that complete protection against homing in to the stream was unlikely to be achieved, attempts to deceive the enemy by use of simulated bomber transmissions in Bomber Support night fighters and to accelerate the development of the bombers' radar aid to blind firing, Automatic Gun Layer (Turret) (A.G.L.(T)) were recommended.

The Restriction of Monica

Before the proposals had been discussed fully with the Air Staff, preliminary flight trials of Monica and a captured specimen of the enemy's Flensburg homer provided evidence that anxiety about the ability of the fighters to home onto a Monica using bomber stream was fully justified, and that homing onto individual aircraft was also to be feared. Views on the future of Monica were, after further O.R.S. Signals discussions, re-stated to the Air Staff. It was re-affirmed that Monica if used at all should be confined to forces wholly equipped with the device, and that its complete

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withdrawal should be considered. A full-scale trial of a large Monica equipped force against Flensburg was recommended as a guide to a final decision. Such a trial was carried out. Details are given in the section of this chapter dealing with Monica and all that is necessary to state here is that the demonstration of the effectiveness of Flensburg which it provided led to a decision to abandon the use of Monica from 12 September, 1944.

The Case for H2S

After this, apart from H.2.S. and a small amount of A.G.L.(T), the radiating devices carried were jamming and communications equipment which need not be used until enemy territory was reached and could be dispensed with altogether if clear knowledge of an associated homing risk was obtained. The question of restricting radiation along the early stages of a route became, therefore, concerned with the use of H2S. The arguments relative to the enemy's exploitation of the H2S transmissions had been clearly stated in the Signals/O.R.S. memorandum to the Air Staff, with the conclusions that urgent consideration should be given to preparations to allow the device to be switched on at operational height close to enemy territory and to experiments designed to assess the need for and the effect of restrictions on its use over enemy territory. Many who had been associated with the development and use of H2S, felt that the value of the device was being underestimated and that any restrictions in its use even if not directly harmful would, owing to anxiety induced in aircrews, lead to a decline in the use of the device and a consequent reduction in the success of bombing operations. There was therefore an acute division of opinion. It was not possible to make a quantitative assessment of the merits of either side and the Command attempted in July and August to treat each operation on its own merits, frequently applying restriction in the use of H2S on the approach to enemy territory. The advance of the allied armies had, however, by mid-September seriously disorganised the enemy's early warning radar system and had thereby given increased importance to the need for preventing the use of bombers' transmissions for long range plotting. The use of H2S. was therefore restricted along the early stages of the route for nearly every operation.

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Although no action was taken by the Command to explore the effects of restriction on the use of H2S over enemy territory, individual groups put their own interpretation on the information available to them about the enemy's homing devices and applied considerable restrictions on radiation. For No. 5 Group these involved the almost complete cessation of the use of the nine centimetre H2S Mark II and restrictions on the use of three centimetre H2S Mark III. This was of course disturbing to those who regarded H2S as an essential aid to accurate navigation and bombing. They argued that even if successful results were obtained temporarily on raids which were not penetrating deeply into enemy territory the expected decline in training and in general interest in H2S would have serious effects on future operations.

The Command Policy Decisions

On 22 September, a Bomber Command conference fully representative of the many branches and establishments within and outside the Command discussed the issues in an attempt to arrive at a firm line of policy. The O.R.S. view put to the meeting was that there could be no question of the necessity to delay switching on H2S on the approach to enemy territory. The military advance had in addition to disrupting the enemy's radar system made possible the use of the navigational aid Gee nearly up to the enemy's frontiers, thereby making the use of H2S on the early stages of the route unnecessary as well as undesirable. Homing on to individual aircraft or into the bomber stream by the use of H2S transmissions were regarded as menaces not requiring immediate action but calling for consideration and preparation. The only argument advanced against this policy was that the delayed switching on of H2S on every operation regardless of the height of approach would involve an increase in the unserviceability of the equipment and the modifications necessary to avoid the risk were likely to take some months to accomplish. The conclusion reached was that the justification for this anxiety should be sought in experience and that H2S should not be used outside enemy radar range when alternative navigational assistance was available.

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The matter was further discussed at a meeting of the Command Tactical Planning Committee on 30 September. The O.R.S. submitted a map of the coverage now provided by Gee in support of the contention that the use of H2S was unnecessary, until the enemy frontier was approached.

The conclusion of the R.C.M. policy meeting was confirmed and the policy became firmly established that the navigational aid on the approach to enemy territory should be Gee for as great a distance as was possible, H.2.S. only being brought into use in time to obtain a good fix before running out of Gee range. Other transmissions, except that from the blind-firing aid A.G.L.(T) were also restricted and the approach of the force without use of its radio and radar equipment became established as a radio countermeasure, known briefly as 'Signals Silence'.

The Case of A.G.L.(T)

A.G.L.(T) was a special case because there were greater difficulties in switching on this device at operational height than there were for H2S. Special consideration was given to it, and it was concluded that so long as the number of sets in the force remained small, radiation could be permitted since the enemy's ability to distinguish by listening between a small number of aircraft carrying A.G.L.(T) and intruder fighters carrying A.I. Mark X was doubted (Report No.B.226 'The Possible Exploitation of A.G.L.(T) transmissions for plotting and Homing').(1)

Signals Silence in Operation

The adoption of 'Signals Silence' as a routine operational instruction did not stop controversy, largely because independent lines of action were still pursued by the groups who were not until 13 October, i.e. three months after the first measures to restrict radiation, provided with an authoritative explanation of the Command policy. This explanation, prepared in collaboration by the Signals and O.R.S. branches and issued over the signature of the Deputy Commander-in-Chief pointed out the great advantages to be gained by denying early warning to the enemy in the 'Signals Silence' approach, but pointed out that no information was available from operational statistics or other sources that homing by fighters onto individual aircraft

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(1) A.H.B./IIH/241/22/12.

was possible. Restrictions on the use of H2S exceeding those laid down by Command were, however, still ordered, particularly by No. 5 Group which was usually operating alone.

The evidence provided by intercepted enemy fighter control radio traffic showed clearly that from September onwards the range of the enemy's first plots on the bomber force was much reduced. Information on the nature of the first plots wss not, however, sufficiently good to enable an asses-ment to be made of the relative contributions to this result of 'Signals Silence', in view of the disruption of the enemy's early warning radar chain by the military advance and improvements in operation of the Mandrel screen.

Comparative statistics on casualties continued to give no cause for anxiety about enemy homing onto individual H.2.S carrying aircraft, and the general reduction in casualties suggested that homing on to the stream was not being accomplished on anything but a small scale. On the other hand, there was no reason to suppose that the Groups' restrictions on the use of H2S had an adverse effect on the success of their operations and an examination of the track-keeping and time-keeping after the introduction of 'Signals Silence' showed that they were similar to those obtaining when H2S was in full use. Although the advice given to and accepted by the Command Air Staff had been against some of the restrictive actions of the Groups, the inclination was to regard these actions in the light of useful experiments since a more severe general restriction had to be visualised as a future requirement.

The Command's policy in this matter was still considered to be unsound in a number of high quarters, and it was agreed that a full investigation into the operation of radiation restrictions should be undertaken by a senior officer of T.R.E. His report, although agreeing that the Command policy was justified, tended to the view that action had originally been taken on insufficient evidence. This, intended as criticism, was in effect a compliment for always in the radio war it was necessary to act quickly on judgements supported by inadequate evidence, and in this case there was absolutely no doubt that the judgement had been correct.

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The Development Stage

Trials were carried out by the Air Defence Research and Development Establishment with T.R.E., with the primary object of exploring the effect of Window on the defences of the United Kingdom, but with the secondary object of deciding the best methods of employment by the Bomber force. These trials were watched by the O.R.S. to ensure that the secondary object received full attention.

On 4 November 1942, the Chief of Air Staff called a meeting of the interested parties to discuss the next step. The prospective value of Window to Bomber Command had therefore to be assessed, and the O.R.S. collected and weighed the available evidence. Calculations based on the results of the recent trials suggested that if the enemy G.C.I. system was to be neutralised by means of Window, about 90 pounds of foil per minute would have to be discharged by every aircraft. It was therefore considered impracticable to use Window for protection along the route. The usefulness of Window was considered therefore to depend on the losses due to radar-aided defences of the target area. Investigation of this and related problems had been and continued to be an unceasing groping. The lines of enquiry available were the reports of aircrews of their observations during an operation, the damage to returned aircraft, intercepted enemy R/T fighter control and odd scraps of information from secret sources. Each source of information required careful interpretation in order to correct the presumed bias in the sample covered. An account of the results obtained from the various methods of approach may be seen in Report No. S.91 'Night Bomber Losses on German Targets, 1942'.(1) In November 1942 the evidence indicated thatlosses were being incurred as follows.

Not due to enemy action	0.5% of sorties
Fighters en route	2.25%
Fighters over the target	0.25%
Flak en route	0.6%
Flak over the target with aid of searchlights.	1.0%
Flak over the target without aid of searchlights.	0.4%
Total	5.0%

It was therefore considered that in view of the prohibitive amount of Window required for effectiveness along the route, the maximum saving to be expected from Window was the loss due to radar-controlled flak at the target

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(1) A.H.B./IIH/241/22/14.

area, i.e. about half per cent of sorties if the searchlights were not radar-controlled and about one and a half per cent if they were. Because of the comparatively small benefit expected, of concern lest Window interfere with H2S and of the much greater benefits anticipated from Monica, O.R.S. opinion at this stage was luke-warm about Window. In consequence, the Command representatives at the Chief of Air Staff's meeting did not press for immediate use of Window in face of Fighter Command's opposition dictated by the serious threat to our own defences which would be produced by presentation to the enemy of knowledge of the countermeasure. It was agreed that consideration of the use of Window should be deferred for six months, this period to be spent in improving counters to enemy use of it and in devising the best methods of use and ascertaining the quantities required for operation of Bomber Command.

Preparations for Introduction

In pursuance of this direction, estimates of the rates of release of Window required to defeat the enemy's control of flak or of fighters by Wurzburgs were made by Fighter Command and by A.D.I. (Science). The Fighter Command estimate was based on a rather stringent requirement for blacking out completely the presentations of the Giant Wurzburg and the Small Wurzburg to ranges of 15 miles and five miles respectively. The rate of release called for was five aircraft echoes of Window per minute from every bomber, although it was suggested that lower rates would produce a useful degree of comparison. A.D.I. (Science) considered that the Fighter Command requirements were unnecessarily severe, but that at the same time they failed to take into account the uneven distribution of Window which would exist within the bomber stream. He concluded that about 5/8ths of the Fighter Command quantity would be sufficient to make the enemy's Wurzburg unusable and that for initial use sufficient confusion could be produced by about one-fifth of that amount. Further, it was considered that, if the Window were released by a special force flying above the bomber stream, the total amount of Window required would be reduced by a factor of two to three. There were many incompletely known/factors involved ~~and it~~ and it was left to O.R.S. to examine the two estimates judicially and to

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arrive at a release rate which would give good hope of success and which could be maintained by the bomber crews. Judgement was pronounced in Report No. S.79 'Operation Window'.(1) The first conclusion was that release by a special force must be rejected owing to a lack of confidence that such a force could keep its position in relation to the bombers sufficiently well. It was considered that the assumptions made by A.D.I. (Science) were in general justified but that, since they were assumptions with only a skeleton backing of fact, a safety margin must be allowed. Moreover, there was some hope that the release of two bundles per minute would affect seriously the enemy A.I. (Fighter Command Report FC/S31389/Sig.J. of 8 January 1943).(2) The conclusion reached was that the preferred rate was two bundles per minute from every aircraft, but that sufficient confusion would be produced on the first few operations by a rate of one bundle per minute along the route with two bundles per minute within 20 miles of the target. The increase rate over the target area was suggested because a comparatively small increase in weight carried could ensure success in an area sure to contain a considerable concentration of Wurzburgs.

The operation considered for the estimates was an attack on Cologne and it was suggested that in view of the wide G.C.I. belt to be crossed, Window release should commence and finish 20 miles from the enemy coast. The conditions assumed, 300 aircraft spread on a front of 20 miles and passing a front at a rate of ten per minute, should, with the height spread of about 7,000 feet, produce a concentration in space of about 0.1 bundles per cubic mile and a release rate of Window of one packet per minute should produce a density of about one Window echo per cubic mile, i.e. about a quarter of the density estimated as necessary to black out completely the Giant Wurzburg presentation beyond a range of 15 miles, even assuming that the distribution of Window throughout the bomber stream was uniform. Considerable reliance was thus placed on the A.D.I. (Science) view that the enemy would be unable to distinguish aircraft echoes from Window echoes. Report No. S.79 recommended that further experimental work should be carried

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(2) A.H.B./ID/12/149.

out in order to determine the form of Window bundle which could with the greatest economy in weight produce the appearance of an aircraft echo both on the Wurzburg and on the Lichtenstein A.I.

The O.R.S. estimate was accepted by the Command and was referred to Air Ministry as the basis for estimating production.

The Final Fight for Introduction

The Chief of Air Staff called his promised further meeting on 2 April 1943, in order to consider the operational introduction of Window. New estimates of the quantities required made as a result of improvement in the form of the countermeasure since the previous meeting in November, had produced a considerable change in attitude towards it since it was clearly now practicable to apply it all along the bombers' route. Accordingly, the O.R.S. view put to the Commander-in-Chief before the Chief of Air Staff's meeting was that 'there was now a good possibility of saving one-third of our losses on German targets by using this countermeasure', and that 'the Command has nothing to lose and possibly much to gain by using it'.

The Chief of Air Staff's meeting at which Bomber Command was represented by the Commander-in-Chief and the Officer-in-Charge O.R.S. agreed to recommend to the Chiefs of Staff that Window should be employed as from 1 May 1943, and to expand the production of the material. This initiated a period of further argument on the merits of Window and of drawbacks which might be expected. The proposals for expansion of production promptly generated a plea that the country's aluminium production would be unable to meet the drain. It was, however, pointed out that a bomber contained about 10 tons of aluminium so that the saving of one or two bombers a night by Window would leave the country's aluminium supply unimpaired.

Other points in connection with the defences of the U.K. and of North Africa arose to postpone the use of Window. The O.R.S. could do little to settle these, but gave continuous support for the earliest possible use by Bomber Command in such discussions as arose.

Preparations for the introduction went on. Methods of launching from bomber aircraft were studied and flights were made to test methods of ejection from existing chutes. The operational area in which discharge should take place

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had to be prescribed. The map of the known positions of the G.C.I. stations was examined and an area embracing them was delineated. It was suggested that the necessary economy in Window would be aided by confining discharge to such an area. This suggestion was accepted and the map concerned was attached to the operational instruction on the use of Window.

As the use of Window became a more probable event, it became evident that some difficulty would be experienced in meeting the Command's needs. The supply position was considered in relation to probable consumption and the conclusion was reached that the production planned in mid-July 1943 would be insufficient to meet operational needs. It was suggested to the Air Staff that initially the release rate should be restricted to one bundle per minute throughout an operation, including the target area, and that shortest possible routes should be taken through the G.C.I. area. This release rate was agreed, with the proviso that future action should be based on the results obtained in initial operations.

First Operational Use

Window came into use for an attack on Hamburg of 24/25 July 1943. For this operation several O.R.S. officers were at squadrons to obtain from the crews first-hand accounts of visible effects of the countermeasure on the enemy defences and of the difficulties experienced in discharging the bundles. They were able from the crews' accounts of the feeble behaviour of searchlights and of the deterioration of flak defences to appreciate that Window had had a telling effect. They also learnt that better methods of opening the bundles, packing them and of ejection from the aircraft, were desirable.

The evidence concerning the first two Window operations was surveyed with great care and was presented in O.R.S. Reports No. S.95 'Immediate Report on the use of Window on Hamburg, 24/25 July 1943,[1] and No. S.96 'Interim Report on the use of Window on Essen, 25/26 July.[2] The success of the countermeasure was assessed taking as yardsticks bomber losses and the indices of enemy defensive activity provided by the proportion of bombers damaged by flak, attacked by fighters and damaged by fighters. The values of these indices for the Window operations were compared with the

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(1) A.H.B./II/69/175(A).
(2) A.H.B./II/70/293.

corresponding values, for operations against the same or similar targets during the previous year. In addition, the intercepted enemy night fighter R/T was combed for evidence of the type and extent of Window interference. This source made it abundantly clear that the enemy was completely confused and was not readily able to distinguish Window echoes from true aircraft echoes, a supposition which had been relied on in estimating the quantities of Window required.

In addition, an attempt was made to determine the position relative to the remainder of the force of the bombers which were lost or of those which, from their reports of damage or attack, had received attention from the enemy defences. It was hoped that in this way to discover how complete was Window protection within the main bomber stream, how adjustments of flying height might make it more complete, and what success the enemy was having in exploiting parts of the force less well protected by Window.

The investigation of individual raids was continued for some time and appreciation of the first ten Window operations was prepared (Report No. S.98 'The Effect of Window on Bomber Operations').(1) The saving of bombers brought about by the use of Window, assessed by comparison with previous experience on similar targets, was estimated as a reduction of rather more than one-third a fraction in good agreement with the forecast made in the previous November. The losses sustained by aircraft bombing in the several individual waves of each operation was considered, and it was shown that the results expected from the changes in Window cover produced by changes in flying height were being realised. Thus, a low flying wave following a high flying wave tended to have low losses whereas a high flying wave following a low flying wave tended to have high losses. Suggestions were made for the ordering of waves in such a way that the greatest benefit from the use of Window would be obtained. These were accepted by the Air Staff.

In addition, an attempt was made to assess the adequacy of the rate of Window release. It was not possible to say that the enemy was having success only against stragglers or high flying aircraft. It was, of course, impossible to discover for certain which, if any, of the aircraft lost

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(1) A.H.B./ID/12/113.

were straggling and only a large effort in analysing navigators' logs could reveal which of the returning aircraft had been on the edges of the stream. (This analysis was considered, but the labour to perform it was not available). The comparison of the losses of separate waves suggested that not very large diminutions of Window concentration were sufficient to give the defences an extra opportunity and that therefore the amount of Window dropped could not, with safety, be diminished. The intercepted enemy R/T traffic suggested strongly that some G.C.I. equipment was still having successes, but it was found impracticable to determine its position with relation to the bombers' route sufficiently well to say whether the victims were stragglers or not. Comparison of the type of orders given in G.C.I. with those obtaining before the use of Window also failed to give a guide as to the extent of Window interference. There was, however, a new form of traffic in addition to G.C.I. apparently involving an alternative, and much looser form of fighter control, and this was taken as some evidence that the G.C.I. system was considerably embarrassed. The absence from the R/T traffic of references to interference on A.I. was difficult to interpret. It was possible that the Window was having little effect on this apparatus, but the possibility that good enemy security had prevented references to A.I. restrained conclusions on this point.

There was thus no good evidence from operations concerning the desirable concentration of Window. It was reasonably clear that no great reduction could be made, and it was recommended that release rates should remain unchanged until further experience had been gained with an improved plan of waves of attack.

Expansion of Production

The success of Window, following a period when the need for secrecy had severely restricted the spread of production, called for immediate planning for expansion of production. Since large quantities of material had to be imported, orders had to be placed to cover a long period ahead and O.R.S. embarked in July 1943 on a task which was to recur at frequent intervals until the end of the European war forecasting the probable future Window consumption of Bomber Command. This involved guesses at the rates of dropping which would be required, the distances likely to be flown through areas where Window release was required, and the probable scale of effort. For the first estimate it was suggested that a stepping-up of release rates to two bundles per minute would soon become necessary and that a further 50 per cent increase within three months must be envisaged. The need for these increases was anticipated owing to the expectation that the enemy radar operators would soon become used to working through Window, and that the enemy's new methods of loose control of fighters might make desirable a reduction in the bomber concentration. The estimated requirements of half-million bundles in August, rising by a quarter of a million bundles per month to one and a half millions in December, was put before a meeting at Air Ministry on 6 August 1943, and was accepted as a basis for ordering materials and equipment.

It was soon evident that production could not be stepped up in time to meet the consumption estimated, and the O.R.S. took on the task of stock-keepers estimating after each operation the amount of Window which had been used from the mileage flown and the number of aircraft taking part, and keeping the Air Staff informed daily of the stock position. On 18 August 1943 the Air Minister set up a panel under the chairmanship of Wing Commander D.A. Jackson at T.R.E., to explore the many problems connected with the necessary increase in Window supply, development of new forms of Window, and launching Window from aircraft. Bomber Command was represented by the O.R.S. on this Window panel which was to continue its work until the end of the European war.

Further Developments of Window against Wurzburgs

Through meetings of the Window panel and personal contacts, close touch was maintained with the M.A.P. branches responsible for organising production and estimates of production were carefully considered together with the figures for stock and consumption in order to prepare for any measure of economy in consumption that might become necessary. In order to prepare for economy measures, study of individual operations was continued. This showed that most of the fighter opposition was met on the return journey and since it was believed that concentration on the outbound route was much better than on the homeward route, a recommendation was made that the rate of Window release should behalved to one bundle in two

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minutes on the outward route as an experiment. This trial was carried out in an operation against Munchen Gladbach on 30/31 August, and no alteration in the effectiveness of Window could be perceived. At the same time, studies of the location of combats and of enemy R/T had shown that G.C.I. was being practised in areas not included in the original Window release zone, and that considerable fighter opposition was developing over the target areas, presumably with the aid of A.I. (Report No. 80 'Some Notes on the Defensive Tactics now used by the Enemy - August 1943).[1] It was therefore suggested to the Air Staff that the area within which Window was to be released should be enlarged, that the rate of discharge within 20 miles of the target should be increased to two bundles per minute, and that the reduced release rate on the outward journey, already tried experimentally, should become standard practice. This was agreed by the Air Staff, and put into effect as from the night of 22/23 September.

Thereafter, the production of Window for use against the Wurzburgs grew steadily and by the beginning of November the estimated consumption appeared to be well covered by the projected production. As production grew and new types of Window came in, it was possible to give more consideration to the packing of the material for the greater convenience of aircrew, and various alterations were considered in consultation with the Bombing Development Unit (B.D.U.) and the appropriate Service branches for the wrapping of individual bundles, the packing of bundles into convenient cartons or parcels, and the provision of launching chutes in aircraft. It should be mentioned here that the B.D.U. had been directed to carry out launching trials in consultation with T.R.E., and the design of special chutes was considered by the Unit. In this work the O.R.S. representative at B.D.U. was able to play a large part.

The consideration of the effects of Window was continued together with appreciations of the effects of tactical countermeasures which had been made necessary by the changing enemy fighter tactics. The methods continued to

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(1) A.H.B./IIK/46/468.

be those employed for the initial analyses. Bomber Command O.R.S. Report No. 80 covered August and Report No. 88 (1) carried on the story to 19/20 November. It was considered on the evidence of enemy R/T traffic that G.C.I. was still attempted but that Window continued to prevent its application to bombers in the main concentration.

In November an attempt was made to estimate the saving of aircraft which could be ascribed to the use of Window. This was prompted by some labour unrest in the firms producing Window ~~produced~~ caused by a lack of understanding of the virtues of the innocent-looking material which they were handling. The estimate was of course extremely speculative. It was based on the fact that losses in 1943, month by month on German targets, had been 0.5 per cent higher than they had been in the corresponding month of 1942. It was assumed that had Window not been used this trend would have continued, and that the losses in the Window-using period would have been 0.5 per cent higher than those of 1942 but for the use of the counter-measure. The actual loss rate was 1.5 per cent lower than the expected one estimated on this basis, and it therefore appeared that every seven tons of Window used had saved an aircraft. This conjecture was widely published as a fact on factory posters.

Window Against Air Interception (A.I.) Equipment

The continued success of enemy free-lance fighters directed attention to the possibility of doing more to defeat the Lichtenstein A.I. When estimates of the necessary Window release rates were made in the pre-operational period, it was considered that practicable rates of release could have little more than a nuisance value to an A.I. operator who had had a little practice with Window. Since that time a specimen of the Lichtenstein had fallen into British hands and the important information about its performance and the possibility of conducting experimental flights with it allowed the problem to be re-examined with more confidence. A note was prepared setting out the expected concentrations of Window estimated as necessary on an arbitrary criterion that half the time-base must be filled with Window echoes to reduce the effective range of the apparatus to various degrees. The concentration of Window suggested as /necessary

(1) A.H.B./IIH/258/1/14.

necessary to produce a serious effect were well in excess of those produced operationally, except possibily over the target. It was, however, pointed out that there was no real knowledge of what proportion of the time-base must be filled by Window echoes in order to make the set unusable, the Window concentrations needed in space must remain speculative. Proposals were therefore made for experiments with the captured Lichtenstein which would produce the required knowledge, and these were forwarded to Air Ministry with a request for speedy action on the trials.

Unfortunately, the projected trials suffered long delays owing to the unserviceability of the equipment or of the aircraft carrying it. Increase in the Window discharge rate was continually postponed, pending the trials results, although the trebling of the bomber concentration by increase in the rate of bombing from November 1943 onwards, and the restoration of the Window discharge rate to one per minute on the outward journey in mid December, did something towards bringing the Window concentration towards that estimated as necessary for neutralising the Lichtenstein.

During May 1944, information was obtained that the enemy was using a new A.I. believed to be working on a frequency in the region 160-180 mc/s. In consultation with the Signals branch it was decided that immediate countermeasures should be prepared. There was a possibility of adapting Mandrel as an electrical jammer, but the technique of preparing long Window had just been mastered and O.R.S. examined the possibility of using such material against the new A.I. (Report No. B.210 'The Use of Window against A.I. on 150-170 mc/s').(1) It was assumed that the A.I. would have somewhat similar characteristics to the known enemy tail-warning apparatus - the Neptune R gerat, and on this basis it was estimated that a launching rate of four bundles per minute would be necessary to black out the time-base at ranges of one mile and above. It was considered, however, that the maximum rate of launching by hand which could be accomplished, since launching of the anti-Wurzburg Window had to be carried on at the same time, would be one bundle per minute per aircraft for most of the route, and two bundles per minute for limited periods. It appeared that this rate would give a useful degree of interference and an estimate of the quantities required for the coming months was prepared, based on the usual assumptions

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(1) A.H.B./IIH/241/22/12

of target, distance and scale of effort. The project was agreed by the Signals branch, and a request was passed to Air Ministry for production to begin on the scale of the estimate.

In June 1944, while the trials were still receding into the future, discussion of interference with the Lichtenstein was again roused by a paper from the Deputy Director of Science which re-stated the view long since put forward by O.R.S. that a release rate of at least five bundles a minute was necessary. It was pointed out to the Air Staff that a sufficient stock of Window was held to permit an increase in the discharge rate, that the weight of the newer types of Window necessary for high discharge rates was, although high, not prohibitive and that the real obstacle to high rates was the ability of the crew to maintain them. It was agreed that a rate of discharge of five bundles per minute or as near to it as crews could manage should be tried over specified areas. The areas for high discharge rates were defined by the O.R.S. after examination of the positions of interceptions reported by crews during the preceding period.

Unfortunately, the trial began in mid-June when the lightness of the night sky made the use of an A.I. almost unnecessary. In any case there followed within a month the discovery that the enemy was replacing the Lichtenstein B.C. by the S.N.2 and further measures had to be sought.

Long Window

In July an intact specimen of the S.N.2 fell by a fortunate chance into British hands, and it then became known with certainty that the new enemy A.I. was working on a frequency of 90 mc/s. The stocks of Window prepared for the 150-170 mc/s band were of course not suitable, but the decision that a low frequency A.I. could be combatted with Window remained and a limited stock of Window Type M.B. prepared for use against Freyas was available. No fresh estimate of the concentration of Window required to combat the S.N.2 was made. The quantity of Window available in any case limited the amount that could be used. It was considered that a release rate of one per minute by half the bombers would produce a useful effect and could be met by existing stocks until new production became available.

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The use of long Window against A.I. began on 23/24 July. No analysis other than a comparison of losses and combats with those of comparable previous operations could reveal the effect of a countermeasure against A.I. The almost simultaneous military advance which gave fresh scope to the Mandrel screen and to other methods of defeating the enemy's early warning system rendered such a comparison difficult to interpret over a long period. However, the evidence provided by the aircraft losses on the first few operations using the long Window left little doubt that a serious blow had been dealt to the effectiveness of enemy fighters.

Although the use of Window was introduced as soon as the general characteristics of the new A.I. were known, it was decided to confirm the effects of the countermeasure by a flight trial with the captured specimen of the device. The trial was also designed to investigate the potentialities of the enemy's Flensburg equipment for homing on to the bomber tail-warning device Monica. The details were worked out by the Signals branch in consultation with the O.R.S. and interpretation of the results obtained was left to the O.R.S.

The plan of the trial was that 100 bombers would fly at heights between 15,000 and 18,000 feet at a speed of as near 160 R.A.S. as practicable on the route Cambridge, Gloucester, Hereford, Cambridge. The earlier stages of the flight were essentially Flensburg trials and are fully treated where Monica is discussed. On the final leg, Hereford – Cambridge, however, half the aircraft were to release one bundle per minute of Window Type MB and a fighter equipped with the S.N.2 was to make attempts to intercept bombers at different parts of the stream. In order to permit assessment of the concentration reached by the force, arrangements were made for photographing the P.P.I. tube of a G.C.I. station and of an Air Ministry Experimental Station Type 11 which would observe the bombers along part of their route. In addition, the aircrews were asked to log accurately the time and height at which their aircraft reached the turning points.

The flight was made by 71 bombers on 30 August 1944, and the analysis of the results obtained was presented on 5 September in Report No. S.175, 'The Trials of Flensburg and S.N.2 Against a Bomber Stream'.(1) The effect /of

(1) A.H.B./II/39/1/1.

of Window on the P.P.Is of the ground equipment was rather serious at the time when photographs were taken and, although an attempt was made to isolate the responses due to Window by observing their rates of movement from successive photographs, no count of aircraft was possible. The photographs, however, yielded a reasonable measure of the width of the bomber stream. The times at the turning points recorded by all aircraft allowed an estimate to be made of the length of the stream and of the distribution of aircraft along it at the various stages of the flight.

The average concentration of bombers during the Window/S.N.2 stages of the trial was estimated as 0.4 per cubic mile, a value similar to that believed to be obtained on night operations. The S.N.2 was completely blacked out by Window except at the head of the stream. It was concluded therefore, that the rate of release used, although below estimated theoretically as necessary, was adequate for operational use.

Thereafter, the development of Window against S.N.2 followed normal lines. Assistance was given through the Window Panel in developing more efficient types and the appropriate branches at Command were kept informed as to the best use which could be made of the several types. The stock position of the M type Window had to be watched carefully, and in changing over production to the more efficient types, care had to be taken that the loss of production in the transition was not too great. In such matters O.R.S. consultation with the M.A.P. branches was frequently needed.

Assessment of the effects of Window against S.N.2 was prevented by the operation of many other powerful factors. It was therefore uncertain whether the amounts dropped were remaining sufficient and when production had been built up sufficiently an increase in the rate of discharge was recommended and accepted. This recommendation was, of course, made purely on judgement of the situation based on the knowledge that the initial rate of dropping could have been barely sufficient for success and that the enemy operators were now well experienced in working through Window and the probability that the enemy would have developed ameliorative technical measures.

One important point common to the use of all types of Window was given special consideration in connection with the use of long Window

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against A.I. Tactical considerations in August 1944 suggested that heavy bomber forces attacking one target should fly on two or more separate routes. Such a scheme would of course have an effect on Window protection. The head of a bomber stream is never surrounded by a sufficient density of Window to give full protection, and the development of more than one head of a stream must increase the proportion of aircraft in positions with deficient Window cover. The effect insofar as it concerned the use of Type M Window against A.I. was considered quantitatively ('A Note on the Effect of several routes on the Concentration of Type M Window ORS/BC Internal Memorandum No. 142). (1) It was shown in this note that the maximum Window concentration likely to be developed in any bomber stream, at the existing rate of dropping and with the presumed standard of navigational accuracy, was unlikely to be more than adequate to impair seriously the usefulness of the enemy's A.I. It was then pointed out that if those separately routed forces were timed to bomb in five minutes, the maximum concentration of Window would only be reached at the tails of the streams but that if the whole of the force was in one stream, bombing over 15 minutes then two-thirds of the force would have the maximum Window cover. This argument was taken into consideration thereafter in the discussion of tactical handling of the bomber force.

The Threat of Centimetric Radar

At the end of 1944 evidence was accumulating that the enemy was developing centimetric radar equipment. T.R.E. were unhopeful of meeting the threat with electrical jamming, and Window appeared to offer the only prospect of a quick counter. The probable rates of discharge required were reviewed, assuming that the German centimetric gear would have similar characteristics to our own. It was estimated that a rate of discharge of 20 bundles per minute could be regarded as a minimum requirement, and that limitations in the capacity of aircraft and in the ability of the crew to discharge would limit the period of Window protection to 30-40 minutes. It was pointed out, however, that since the enemy would probably use a frequency in our own 10 cm band, our centimetric equipment would be interfered with by the use of Window. It was also suggested that so long as hand-launching of Window was necessary, use of centimetric Window should

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(1) A.H.B.2 unindexed.

be confined to chosen parts of the route where half the force should change over, the remainder continuing to discharge the other types. At the concentrations then being achieved this reduction in the rate of discharge of the Wurzburg and S.N.2 Window appeared to be without grave risk, especially if electrical jamming of S.N.2 was available. The rate of discharge recommended for centimetric Window was ten bundles per minute, this being considered sufficient to cause some confusion in an A.I., although allowing it a useful range to complete black-out. On this basis the Command requirement for centimetric Window was estimated as two million bundles per month. This estimate was agreed on and put to Air Ministry. Then followed many discussions on how to meet the requirement at the Window Panel and with M.A.P. officers. The steps taken affected the Command only insofar as it was considered desirable to cease the use of centimetric Window on Bullseye exercises. It is not necessary to give details of the other measures taken but it may be mentioned that at the close of the European war the Command had been made able to use countermeasure Window against centimetric equipment appearing anywhere in the band 7-12cms.

Window Feints - Preparatory Work

The use of Window as an aid to feint operations has been referred to in the section dealing with Mandrel and special variants of this use are dealt with in the section on Operation Overlord. It is appropriate to deal here with some aspects of this important application which are specifically concerned with the fundamental properties of Window.

The need for feint operations in support of the re-entry into Europe stimulated the development and production of a form of Window (Type MB) capable of producing aircraft responses on the enemy's early warning sets. At this time (April 1944) the provision of Mandrel was well below that necessary to cover the bomber force against the enemy early warning system, and there appeared to be no prospect of improvement in main force fitting. There was, however, a prospect that a small number of aircraft would be equipped with jammers covering the whole frequency band of the known

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enemy early warning sets. The various possible combinations of Window and Mandrel were discussed in Report No. S.148 'The Possible uses of Freya Window and Mandrel against the Enemy Early Warning Equipment.[1] It was considered that three objects should be aimed at: concealment of the approach of the bomber force along the early stages of the route, prevention of accurate plotting of the force, and interference with Freya-aided G.C.I.

In order to study the possibility of concealment of approach, a map showing the positions of enemy coastal radar stations and their estimated coverage was prepared. It appeared that to conceal the position of a force at a distance of 50 miles from the enemy coast by means of Window an area of at least 100 x 100 square miles would have to be infected with the Window echo every two square miles. It was estimated that 50 aircraft would be necessary to lay such a screen, whereas there was a good prospect of producing a more effective Mandrel screen with 20 aircraft. Window, however, concealed the size of the force and could therefore serve in the simulation of large scale attacks by means of small forces. The combination of such feints with the use of a screen of Mandrel aircraft was considered to offer excellent possibilities of confusing the enemy's plotting. The amount of Window and the number of aircraft required to produce a successful feint had to be estimated from first principles. The estimate was based on the characteristics of the enemy early warning sets as the proposal did not envisage that the feints would approach within range of precision radar. The argument ran that to simulate a force of 400 aircraft at least 400 Window echoes must be produced during the length of 'life' of the Window, taken as 10 minutes and that the echoes must be spread over an area likely to be occupied by such a force. This area was taken as 60 miles long and 20 miles wide and therefore it was considered that 200 echoes were required every 10 minutes in each of two consecutive 30 mile lengths. It was argued that Window bundles dropped closer together than the pulse length of the Freya would not give separate echoes, and that in order to avoid the appearance to the enemy radar of a series of separate trails, the separation of aicraft across the stream should not be less than two miles. On these bases it was estimated that

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(1) A.H.B./IIH/241/22/14.

a force of 25 aircraft each releasing two Window echoes per minute would be adequate. Since two bundles of Type MB Window were required to produce one aircraft echo, this was equivalent to a release rate of four bundles per minute. As, however, the feint force would leave a trail of dying Window echoes, the main force ought also to leave such a trail, and [redacted] therefore a few aircraft towards the head and the tail ought to release long Window on the approach to enemy territory.

For the flight over enemy territory it was estimated that the use of Freyas for G.C.I. purposes at ranges of 20 miles or more could be prevented if the density of echoing bodies was one per two square miles. It was considered, therefore, that the density of bombers alone should be sufficient to prevent the use of Freyas for G.C.I. except on the fringe of the stream. The possible extra protection which could be given to aircraft on the fringes by the use of long Window had to be weighed against the interference with Monica which would be caused and the additional effort involved by discharge of more Window. Judgment was given against the use of Window. The concealment of the direction of flight of the force over enemy territory clearly could not be achieved by Window and it was therefore considered that release of long Window by the main force would not be worthwhile except as mentioned above, on the approach to enemy territory in order to prevent distinction between main force and feint.

The recommendations were agreed by the Air Staff and a more detailed investigation was then made into the best methods of employing a Mandrel screen and Window-aided feints. Some particulars of this investigation were given in the section of this report dealing with Mandrel and the results were presented in O.R.S. Report No. B.216 'Proposals for the Tactical Use of the Mandrel Screen'.(1) It is necessary to refer here only to a slight change introduced into the Window release proposals. In examining the coverage of the enemy's coastal radar, it was considered that an effective feint force would need to approach within range of the Giant Wurzburgs. The recommendation was made, therefore, that the aircraft of the feint force should release Window covering the frequency band of the

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(1) A.H.B./IIH/241/22/12.

Radio Countermeasures in Operation Overlord

Introduction

The re-entry to the Continent in 1944 was clearly an enterprise which called for maximum efforts to achieve surprise. Since a principal agency against surprise was the enemy radar system, an elaborate plan of destruction and deception was prepared against that system. The general requirements for Radio Countermeasures in support of the landing operations were laid down by the Naval and Air Staffs concerned in consultation with T.R.E. and others, but much of the detailed planning of the R.C.M. operations necessarily devolved on Bomber Command, at that time the only Command having large-scale experience of R.C.M. and possessing the required devices. This detailed planning was the responsibility of the Signals branch, but at all stages of the preparation the programme was discussed by a joint Committee of Signals and O.R.S. staff.

A full account of the plan finally prepared and successfully carried out has been given elsewhere.(1) Briefly, the plan involved the simulation by means of Window released from aircraft of convoys approaching two parts of the coast, the provision of a Mandrel screen to cover the approach of airborne forces, simulation of airborne forces by Window and the jamming of enemy V.H.F. communications by means of A.B.C. The mode of operation of the Mandrel screen and of the A.B.C. aircraft was settled in discussion between Signals and O.R.S. representatives. The methods used were essentially those used in planning the Mandrel screen for bombing operations (Report Nos. S.148 and B.216).(2) The development of the schemes for Window feints called, however, for a specific study by O.R.S.

Window for Operation Overlord - First Proposals

The requirement for the use of Window originally made was to supplement electrical jamming in order to black out the enemy radar observation of three areas in the Channel, and to provide cover for the airborne forces. These projects were duscussed at T.R.E. who had been concerned with the broad plan and had proposed many of the schemes, and a detailed scheme was then prepared (Report No. B.202 - 'An Estimate of the Window and Aircraft required to provide cover requested by A.E.A.F.'). It was considered that /the

(1) A.H.B.Narr. The Lib. of N.W. Europe, Vol.III.
(2) A.H.B./IIH/241/22/14 and A.H.B./IIH/241/22/12.

the best means of producing a complete black-out either for the concealment of surface forces in the channel or for covering the approach of the air-borne forces was to release Window in sufficient quantity to produce a dense cloud of dispersed dipoles rather than to rely on filling the time-base of the enemy radar with discrete echoes from individual bundles as was the practice in bomber operations. The T.R.E. recommendation was that in order to achieve this effect, four times the amount of Window needed to fill the time-base with discrete echoes would have to be released. A calculation was therefore made of the Window density required to fill the time-bases of the enemy coastal radar installations, Giant Wurzburg, Freya and Seetakt, situated in the most favourable position, for observation with the discrete echoes at the shortest range at which black-out was required. This density multiplied by four was then assumed to be the density to be aimed at for complete black-out.

The areas required to be blacked out were 20 x 15 miles, but it was considered that this should be increased by ten miles in each direction to allow for navigational error and wind drift of Window. It was estimated that the Window released from one aircraft would cover a lane of width three miles, and that therefore to cover the required front of 30 miles, ten lanes of aircraft would be required. Since renewal of the Window was required every 15 minutes, the total distance to be covered in 15 minutes was double the depth of the area (25 miles) for each of 10 lanes. 10 aircraft flying at a true airspeed of 200 m.p.h. would thus be just able to deal with one area, flying along paths three miles apart to and from the coast, releasing Window on the runs towards the coast.

It was estimated that each aircraft would need to discharge Window bundles at the following rates per minute; 72 for Wurzburg frequencies, 12 for Freya frequencies, and 6 for Seetakt frequencies, i.e. 90 bundles per minute for all types. Although it was suggested that the rate of release could be made practicable by packing the Window so that the equivalent of four bundles could be released simultaneously and by providing additional crew and launching positions, the total quantity of Window to be carried by

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each aircraft for the screening of the Naval forces was estimated at 2,275 pounds, occupying a space of 55 cubic feet. The amounts required for the screening of the airborne forces were somewhat less, but were still formidable. It was recommended that the stowage and launching problems be explored immediately.

It was decided by the Air Staff that Wellington aircraft of the O.T.Us should, if possible, perform the operation because a full effort from the bomber force would be required for other purposes. An O.R.S. representative therefore, visited an O.T.U. to investigate the stowage and launching problems in the Wellington. Trials of Window stowage and launching were carried out under conditions of flight similar to those expected on the operation. It was concluded that subject to a few minor modifications to the aircraft and to the packing of the Window, the proposals made were wholly practicable. A revised version of Bomber Command O.R.S. Report No. B.202 was issued on 24th March, 1944, incorporating the proposals for stowing and launching resulting from the trials. Training for the operation began in No. 92 Group and, after some experience had been gained, various problems concerning navigation and the arrangements for training were discussed with the group representatives.

Plans had just been worked out when a revision of the part to be played by Window was proposed.

Window for Overlord - Final Scheme

Two of the areas in the channel which it had been proposed to drench with Window were not to be used by real assault forces but were intended as feints. It had been suggested by T.R.E. that realistic feints could be produced if Window were used to simulate naval forces. Initial opinions had not been very favourable to such a scheme owing to the high degree of navigational accuracy which would be required for its success, and the black-out shceme had therefore been developed. However, trials on a limited scale conducted by the Royal Navy and the Allied Expeditionary Air Force, with T.R.E. help showed that the scheme was by no means impractical. A request was made, therefore, to Bomber Command that such a plan be substituted for the one under active preparation. It was proposed in addition that the airborne forces should be protected by the use of Window aided feints instead of by direct screening.

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The proposals were discussed between representatives of the Signals and O.R.S. branches of Bomber Command, A.E.A.F. and T.R.E. on 18 April 1944. The plan for simulation of a convoy which had emerged from the trials was that aircraft flying very accurately on elliptical orbits about 10 miles long releasing Window of appropriate type along the straight runs of the orbit, which were to be two miles apart and should at each successive orbit approach nearer to the coast by the distance which a convoy would move during the orbit time. In order to maintain the illusion of a surface force the sizes of Window bundles were to be adjusted as the orbitting aircraft approached the coast in order that the size of echoes produced should vary in accordance with the change in echoing power of surface targets with distance. It was agreed that arrangements would be made to try out the proposed scheme. These were to include the provision of a radar site suitably equipped and situated relative to Gee lattice lines similarly to the operational area. The O.R.S. was asked to prepare a detailed scheme for the aircraft flights and Window release.

The broad outlines of the type of flying and accuracy of navigation required were discussed with No. 92 Group on the basis of the experience gained in this training for the initial scheme. It appeared that the use of Wellington aircraft with O.T.U. standards of navigation would not permit a scheme wherein each aircraft completed an elliptical orbit and an alternative plan was prepared which involved an accurate run along a Gee lattice line in one direction only. This of course doubled the number of aircraft required. A further increase in number of aircraft was necessitated by the fact that three boxes of orbitting aircraft were required in order to produce the desired length of 'convoy' instead of the two boxes hoped for. It was, however, considered thatfurther trials should be made with a view to retention of the elliptical orbit.

The size of Window bundle required at the several stages of the simulation was estimated from T.R.E. reports on the echoing properties of surface targets. It was estimated from reports on the initial trials that the operation could be performed with six sizes of bundle, a schedule of the

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times for release of bundles of the appropriate size was prepared, and the total requirements for the various sizes of bundle was calculated. Suggestions were made for packing this special Window in ways which would facilitate the change over from type to type in the aircraft.

Similar estimates were made for the planned simulation of airborne forces. The results of these considerations (Report No. B.206 'An Estimate of the Window and aircraft required for the Revised A.E.A.F. Plan' - 22 April 1944) (1) were forwarded by the Air Staff to SHAEF.

T.R.E. also gave consideration to the problem (Report No. 5/M91/RC 'Use of Window to simulate low level targets in enemy radar' - 28 April 1944) (2). They suggested that sufficient navigational accuracy would be achieved if the elliptical orbits were flown, and accurate fixes obtained only when the aircraft turned off the straight run, reliance being placed on accurate turning to position the second straight leg of the orbit. The T.R.E. proposals for Window bundle sizes differed immaterially from those made in the O.R.S. report which were already being acted on. The navigational problems were discussed between T.R.E. and O.R.S. and trials agreed on.

Meanwhile, discussions had been carried on at Bomber Command between O.R.S. and Signals which resulted in a conclusion that the Window feints required a navigational standard above that of the O.T.Us. Therefore, the recommendation was made to the Air Staff that, although simulation of the airborne forces could remain an O.T.U. commitment, the convoy simulation should be made the task of a three flight operational squadron. As a result No. 617 Squadron was nominated to prepare for the convoy simulation. The Squadron Commander was called into discussion at Bomber Command on 7 May 1944, the basis being an O.R.S. memorandum summarising the scheme laid down in O.R.S. Report No. B.206 and embodying the results of discussions with T.R.E. on the navigational problems. It was agreed that the necessary training should begin immediately, and that an attempt should be made within a week to decide whether the operation would be practicable.

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(1) A.H.B./IIM/al/4a (22 Apr. 1944).
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An O.R.S. representative visited the squadron to explain and discuss the scheme with the navigators, assist in arrangements for training, and in the assessment of results. It was quickly apparent that although training flights could be made anywhere, assessment of the accuracy by means of ground photographs presented great difficulties, and it was recommended that the coastal radar site which had been allotted for trials of the simulation should be used throughout training. This was arranged, and it was soon shown that the squadron would be capable of performing the operation with the accuracy required. When this was established, the further development of the navigational technique was left to T.R.E., while O.R.S. paid more attention to the Window aspects. The development of several new types in addition to the special bundles for the convoy simulation was then going on in order to cover Seektakt and Freya frequencies and in order to have double units for use in high rates of discharge. Questions arising on the suitability of these types and of their packing for the tasks in hand, the production of the necessary quantities and their despatch to the correct destinations were a constant responsibility.

The method used by No. 617 Squadron relied entirely upon the navigational aid Gee. Since the operation was to be performed at low level doubts were felt about the reception of Gee pulses in the proposed operational areas. Test flights showed that in one of these areas, the doubts were fully justified. Means of overcoming the difficulty were discussed at Bomber Command and a possible solution appeared to be the use of a combination of Gee and another navigational aid Gee-H. This solution was adopted by the Air Staff, and the only squadron trained in the Gee-H technique, No. 218, was allotted the convoy simulation task in one area, No. 617 Squadron being left to cover the area in which Gee was adequate for the task.

The O.R.S. representative who had already been assisting No. 218 Squadron in Gee-H training was delegated to assist in the special training, and it was soon established that this squadron also would be able to perform the required operation. Thereafter, no major changes had to be made,

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although numerous points arose as the operational plan as a whole became more clear. These were normally settled in the Signals/O.R.S. discussions.

When the time came for the issue of final operational instructions, the O.R.S. prepared schedules of Window release and, in conjunction with T.R.E. and the Signals branch, prepared detailed navigational instructions for each aircraft, including the Gee and Gee-H co-ordinates required for the turning points of every orbit. The operations were carried through with every appearance of success, and as became known later contributed considerably to the surprise effected by the assault.

The simulation of airborne forces involved little preparation. The plan as laid down in Report No. B.206, with the amendments made necessary by changes in the places and times of operation, was carried through without trouble.

CHAPTER 18

COUNTERMEASURES AGAINST ENEMY COMMUNICATIONS AND AIRCRAFT

Brief History of Jamming

Countermeasure Tinsel was introduced in December 1942 to jam the German radio telephony link between ground control and individual night fighters which was vital to his G.C.I. system of fighter defence. This R/T was carried on in the frequency band 3-6 mc/s, the High Frequency (H.F.) regions of the spectrum. Jamming was applied by the wireless operator in every bomber.

In March 1943, a switch of some of this fighter control traffic to the Very High Frequency (V.H.F.) parts of the spectrum was observed. The change over progressed steadily, the new frequencies lying in the band 38-42 mc/s. A counter to the V.H.F. communication was brought in during August 1943 as Ground Cigar, a jamming transmitter operated in this country, and this was improved upon in the following October by the use of airborne Cigar or A.B.C. carried by a few aircraft within the bomber force.

The enemy largely abandoned his G.C.I. system of fighter control in August 1943, consequent upon the introduction of Window, and adopted methods of directing fighters <u>en masse</u> towards the bomber stream. For this purpose he was able to use a broadcast from one or more high-powered transmitters. The first attempt to jam this broadcast 'running commentary', which was transmitted on H.F. in plain speech, was to transfer two-thirds of the Tinsel effort to the frequencies used for it, an operation named Special Tinsel. The enemy reacted with an increase in the number of frequencies employed and Special Tinsel was reinforced in October 1943 by a transmission from ground stations in this country, operation Corona. These ground stations did not initially attempt to jam but, instead, transmitted confusing and irrelevant information in German speech.

Thereafter, a series of enemy attempts to find a channel of communication free of jamming was followed step by step by the introduction of additional countermeasures. The use of high-powered broadcasting stations in the M.F. band was attacked by ground jammers in operation Dartboard, attempts to use W/T on the H.F. band were met by ground transmissions of Drumstick and M.F. radio navigational beacons attempting to pass information were countered by Fidget also ground-based.

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During the later half of 1944 the existing countermeasures were reinforced by Jostle, a high-powered airborne jammer fitted in specialist aircraft of No. 100 Group directed first against H.F. transmissions and later also against the V.H.F. band.

Methods of Assessment

So long as the communications countermeasures were confined to monitored jamming applied by individual aircraft, Tinsel and Airborne Cigar, it was possible to deduce something from aircrew reports of the effectiveness of the operation. Special reports were therefore laid on for these operations and were analysed by the O.R.S. When Tinsel was the only communications jamming there was also a prospect of observing an effect on the proportions of aircraft missing or intercepted by fighters in the manner used for assessment of countermeasures to radar. However, when the measures multiplied it was no longer possible to estimate their individual contributions. The only method of assessing effectiveness was to observe the enemy's reaction. This was a question for Intelligence, in particular for the monitoring services. The extension of the countermeasures to frustrate the enemy moves was a technical matter in which also the O.R.S. could not play a large part. There were many discussions involving the Signals branch and T.R.E. on the extent to which it was profitable to deflect effort from radar jamming or tail-warnings to communications jamming. In these the O.R.S. participated but was not able, after the initial phase, to offer advice based on operational results. Therefore, detailed consideration will be given only to Tinsel and Cigar, the countermeasures which did permit and require active O.R.S. consideration.

Tinsel

Preliminary Discussions

In September 1941, a wireless operator flying in a Hampden aircraft of No. 5 Group over Holland heard German speech on his receiver. Thinking that this might be fighter control traffic he tuned his transmitter to the frequency of the German transmission and screwed down the key. After 4 or 5 minutes he let up the key and was gratified to hear the German still apparently trying to pass the same message. The report of this incident gave rise to the suggestion by the Chief Signals Officer No. 5 Group that the idea should be extended and at Command this suggestion was referred to the O.R.S. for exploration. However, before much

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progress had been made with the collection of information on the number of frequencies used in the German control, a policy decision was given against systematic jamming for fear that it should provoke retaliation. The project was, however, revived during 1942 when the Royal Aircraft Establishment (R.A.E.) developed a simple means of using the bomber Marconi set T.1154 and R.1155 to jam the enemy R/T used for fighter control on the 3-6 mc/s band. In the R.A.E. scheme the bomber transmitter could be modulated by noise applied by means of a microphone installed in an engine nacelle. The wireless operator in each bomber was thus enabled to transmit a potentially useful jamming noise to any enemy R/T found by search with his receivers.

There seemed every likelihood that the use of jamming of this type would be overcome by the enemy introduction of V.H.F. for his fighter communications, and it was argued by some that to precipitate such a change would be to encourage an improvement in efficiency. At Bomber Command, however, it was judged that the introduction of V.H.F. would come sooner or later whether or not jamming was applied and that there was everything to be said for securing an immediate benefit by jamming the existing H.F. communications band while it was possible. This view was accepted and jamming of the enemy H.F. R/T was adopted as a countermeasure under the name of Tinsel.

First operations

Tinsel was brought into operational use on the night of 2/3 December 1942. Full operational details are contained in Bomber Command Signals Instruction No. 17 but the following brief outline contains the essentials. Each Group allocated a band of 150 kc/s to each of its aircraft operating so that the whole of the enemy band was covered by every 20 aircraft from each Group. The wireless operators were instructed to search their allotted band and to back-tune their jamming transmitter to any German R/T heard at good strength. Jamming was to be carried on for about 30 seconds and then lifted for a check on the persistence of the R/T. If necessary it was to be resumed for 30 second periods until enemy R/T could no longer be heard at good strength. The wireless operators were to log the frequencies jammed with any details of the apparent effects.

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The sources of information available for investigation of the effects of Tinsel were the wireless operators' logs and the records of the service monitoring the German R/T at ground stations in this country, which was under the control of Air Intelligence 4 (A.I.4). For the first operations of Tinsel every detail provided in these records was considered most carefully. The information from both sources was plotted out against scales of time and radio frequency, under such classifications as: aircraft report of effective jamming, aircraft report of ineffective jamming, aircraft report of jamming by another aircraft, two or more aircraft report jamming without reporting each other, A.I.4 report of unjammed traffic, A.I.4 report jammed traffic. By this means it was hoped to discover what gaps were being left in the enemy frequency band and the accuracy with which the wireless operators were tuning their transmitters to the enemy frequencies.

After two operations an appreciation of the results was made.[1] The reports of crews and of A.I.4 indicated a considerable degree of effectiveness in the jamming. Although some effort was wasted on non-military broadcasts, the whole enemy frequency band used for fighter control seemed to be adequately covered. Apparent enemy attempts to avoid jamming by frequency change were noted. The effect of Tinsel on casualties was obscured to some extent by the introduction of another countermeasure - Mandrel - aimed at the enemy's early warning radar, on the second operation. However, comparison of losses and interceptions by fighters with those on previous operations against targets in the same area indicated a promising result for Tinsel.

In order to assist in the investigation, arrangements were made for representatives of O.R.S. and the Signals branch to listen to the enemy traffic and the Tinsel at Headquarters Bomber Command on the night of 20/21 December 1942. This direct method of approach produced several interesting indications. Those bearing on the efficiency of the operation were the tendency of some operators to keep their jamming transmissions going for too long without a break, the incompletely satisfactory modulation of some Tinsel transmissions and the waste of effort on traffic not concerned with operational fighter control. An additional important result was that enemy traffic and Tinsel were intercepted at times and on frequencies not recorded by the monitoring stations under A.I.4 control.

(1) O.R.S. Report No. S.75 'Interim Report on Jamming of Enemy R/T by Bomber Aircraft'. (A.H.B./II/69/287).

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These results with recommendations for remedial measures and some comments on the results obtained from analysis of logs on other operations were presented to the Chief Signals Officer.(1)

Those of the recommendations appropriate for such action were transmitted by the Signals branch to Groups for the information of aircrew. These were that operators should limit their period of jamming more strictly and that they should listen repeatedly to recording of enemy night fighter control traffic, in order to avoid wasting their jamming efforts.

Air Ministry was advised of the discrepancies between the traffic picked up at Bomber Command, at the A.I.4 listening stations and in aircraft on operations and the suggestion was made that an additional listening station should be provided in order to capture traffic which existing ones might miss owing to skip effects. As a result, O.R.S. representatives visited the headquarters of the monitoring system to discuss the difficulties. Direct contact with the listening organisation did much to clarify the position. It appeared that the differences in the amount of traffic recorded by the official monitors and by other ground listeners were due largely to varying interpretation of the nature of the traffic heard, although in the case of aircraft reception, position relative to the transmitter was also a considerable influence. These discussions and subsequent considerations by A.I.4 led to the promulgation of some revisions to the Tinsel procedure.(2) These included a revision of the distribution of the wireless operators allotted frequencies for search in order to give improved cover over frequencies of 3-4 mc/s which the A.I.4 records showed to be used more intensely than the remainder of the band in night fighter control. Emphasis was also placed on the need for speed in operating Tinsel and for jamming all German traffic heard at good strength in view of the short period found to be taken up by a successful interception and of the rapid changes from practice messages to operational traffic which had been observed.

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(1) O.R.S. Memo. M.155 - 'Tinsel Operations', 8/21 December 1942.

(2) Countermeasure Tinsel - Bomber Cmd. File BC/S.25707/Sigs of 29 January 1943.

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An unusually large number of casualties on a small-scale operation undertaken in December 1942 had directed attention to the employment of countermeasures on such operations. There was, apart from this one operation, no operational experience of Tinsel on small raids and a recommendation had to be made on general grounds.(1) It was considered that Tinsel was having a useful effect on morale and that to discontinue it for small operations would damage this effect. The proposal was made, therefore, that pending findings from operational experience Tinsel should be used on small scale operations, and a revised system of allotments of frequency bands to wireless operators was prepared to cover operations made by less than 40 aircraft.(2)

The Efficiency and Effectiveness of Tinsel

Since any effect of Tinsel on aircraft losses was likely to apply to the bomber force as a whole, the only standard of comparison for an estimation of its size was the loss rate of the force before the introduction of Tinsel. This was not a very satisfactory standard since, in addition to the changes of season, targets attacked and types of aircraft which always beset comparisons of different periods, the introduction of countermeasure Mandrel had occured almost simultaneously with the start of Tinsel. The Mandrel operation was the jamming by airborne and ground transmitters of the Freyas, the radar installations used by the enemy to gain early warning of the approach of the bombers to his coast and to assist in the early stages of controlled fighter interception. It was thus likely to produce effects rather similar to those expected from Tinsel, a reduction in the number of interceptions by fighters and consequently also in losses.

An attempt was made to sort out the effects of Tinsel from those of the other factors.(3) A comparison was made of the bomber losses and fighter attacks for operations against German targets during three monthly periods between the period before the introduction of Mandrel and Tinsel, the period after the introduction and the corresponding periods a year previously. It was shown that the increase in losses and attacks over those of a year before declined appreciably after the introduction of the countermeasures. Thus, it appeared probable that Tinsel and Mandrel were having some effect. The evidence provided by interceptions of enemy

(1) O.R.S. Memo M.156 - 'Suggestions for the use of Tinsel on Small Operations'.

(2) These recommendations were embodied in an amendment to Bomber Command Signals Instruction No. 17 ('Countermeasure Tinsel - Application to Operations involving small numbers of Aircraft').

(3) O.R.S. Memo M.158 - 'Report on the Jamming of Enemy H.F. R/T by Bomber Command Aircraft, Operation Tinsel'.

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take-off and landing traffic suggested that on some nights the scale of enemy fighter effort had been comparatively low, an effect attributable to Mandrel or to fog over fighter bases or to both. However, considering nights on which the fighter effort appeared to be normal, it appeared that losses were unexpectedly low on operations conducted in moonless conditions. This was suggestive of a benefit from Tinsel which, it was considered, might well be more effective on dark nights when fighters without A.I. would need ground control to bring them closer in to their target than on moonlight nights.

The night fighter control traffic logged by the listening stations was examined in order to determine the proportion of attempts at interception which led to combat. This proportion showed a slight tendency to decline after the introduction of Tinsel and was especially low during the period containing the dark nights when losses were comparatively small.

There was thus evidence that Tinsel was serving a useful purpose but a theoretical estimation of the potentialities of the countermeasure suggested that the full effect was not being realised. This estimation was based on an assumed value of the power of the enemy transmitter and on values for the concentration of bombers derived from analysis of navigators' logs. The relative distances of a fighter from its controlling ground station and from a Tinsel operating bomber for jamming to be effective were calculated, and from these the average number of aircraft providing protection to a particular bomber were derived for various bomber concentrations. Applying the results to actual operational data of bomber concentration and the number of interceptions by fighters, it appeared that with an effective range for Tinsel of six miles nearly half the attempts at interception should be frustrated. This effective range seemed reasonable since, on the assumed value of the enemy transmitter power, a fighter six miles from the bomber would be unable to receive its ground Station's transmission at a range of over 15 miles. This estimation was, however, based on the assumption that all the aircraft applied Tinsel with 100 per cent efficiency, and it appeared that the failure to realise more definite results might be due to inefficiency in application. Further attention was given, therefore, to the wireless operators' logs.

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The examination of these records and of reports of the ground monitoring system had been continued throughout the operational use of Tinsel. Although it was not possible to go into great detail for every operation, selected operations and periods were given special attention. The distribution of frequencies logged by wireless operators as jammed showed pronounced aggregations within ± 10 kc/s of frequencies recorded as operational by the ground listening service. It appeared likely that scatter within these aggregates was due to unavoidable errors in dial reading and, on this basis, more than 50 per cent of the jamming effort seemed to be directed against frequencies likely to be used in fighter control. Nevertheless, the ground watch reported many of these frequencies as not jammed effectively. Although this did not necessarily mean that jamming was not effective at the position of the fighter, when considered together with the disappointing effect on losses, it gave rise to some disquiet and suggestions were passed to the Signals branch for testing the accuracy of the operators' back-tuning.(1)

No action was taken as the expected effectiveness of Tinsel was reduced by two events, a spread in the use of V.H.F. which put much enemy fighter control beyond the reach of Tinsel and the introduction of countermeasure Window which dealt a severe blow to the enemy's system of control of individual fighters. In August 1943, operation Tinsel was modified to include the use of Special Tinsel, the application of the jamming effort of the whole force to a frequency determined in this country as one used for the control of fighters <u>en masse</u>. This initiated a phase of communications jamming which involved so many factors that no further attempt to sort out the effects of Tinsel could be made.

<u>Cigar</u>

<u>Planning</u>

At the beginning of April 1943 the listening service engaged in monitoring the German R/T used for control of night fighters in the G.C.I. defence system obtained clear information that transmissions were being made on frequencies in the band 38-42 mc/s. Previously the traffic had been confined to frequencies of 3-6 mc/s and was being jammed by Tinsel. Means for jamming on the new frequencies became available in a ground-based transmitter, Ground Cigar, operational at the end of July 1943, and in an airborne jammer, Airborne Cigar or A.B.C. operational

(1) O.R.S. Memo M.157 - 'A Note on the Efficiency of Tinsel Jamming'.

in October 1943. The A.B.C. installation for a single aircraft consisted of means of search for enemy signals and three transmitters tuneable to the frequency of selected enemy signals. The problems concerning Ground Cigar were not studied by O.R.S. but considerable attention was given to the operation of Airborne Cigar.

After some preliminary informal discussions, a meeting of representatives of the Operations, Signals, Intelligence and O.R.S. branches was convened at Bomber Command in August 1943 in order to discuss the operational application of A.B.C. The first requirement was to estimate the number of jammers required and to decide their distribution along the bomber stream. O.R.S. represented that the number required must depend on the size of the force operating and it was agreed that there should be one A.B.C. carrying aircraft for every 10 minutes spent by the bombers over the target, plus one, and that they should be spaced at regular intervals along the stream. O.R.S. recommended that before the details of the mode of operating the jamming were decided, a survey flight should be made by an aircraft carrying the receivers of the A.B.C. equipment, and that in operational flights operators should log the traffic heard in order to provide information necessary to plan operation for maximum efficiency.

The operational use of A.B.C. was discussed further at the 6th Meeting of the Bomber Command R.C.M. Committee on 28 September 1943, after the proposed survey flight had been made. The survey had shown the possibility of distinguishing between three types of V.H.F. traffic; the running commentary broadcast to groups of fighters, G.C.I. control of single fighters and the system of long range control of single night fighters known as Benito. It was agreed after discussion that the jamming effort should be directed at the running commentary until 10 minutes after leaving the target area, and thereafter the three strongest signals should be jammed.

Operational Use

A.B.C. was installed in aircraft of No. 101 Squadron only, and was first used operationally on the night of 7/8 October 1943. The instructions laid down for the conduct of the operation were those agreed in the various discussions mentioned above, except that eight A.B.C. aircraft were laid down as the minimum requirement for support of the force.[1] The instructions included provision for log-keeping

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(1) Bomber Cmd. Signals Instruction No. 20.

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by the operators and for an analysis of the contents of the resulting logs to be made at the squadron. The squadron requested assistance for this analysis, and an O.R.S. representative was attached for a period to develop the means of extracting the maximum useful information.

The investigation at the squadron was aimed primarily at discovering what information could be derived from records of the signals received. In addition, a check was made on the navigators' logs of the A.B.C. aircraft in order to ensure that they were spread as required along the bomber stream. Technical problems arising were dealt with by a Signals officer. It was soon apparent that the operators' logs could yield some useful information. The aircraft receivers were able to pick up enemy transmissions which were beyond the range of reception of ground listening stations in this country, and there was therefore a possibility of establishing facts about the persistence of G.C.I. and of the frequencies on which running commentaries were broadcast. It was also hoped that signal strengths of the running commentaries as received by aircraft in different positions would enable the sites of the transmitters to be estimated.

The discovery of transmitter sites was found to be almost impossible without sacrificing efficiency of the jamming operations. The operators had to control the size of signal as presented on the visual indicator to suit their individual needs, and were in any case embarrassed in measuring amplitude of signal by Cigar transmissions from other aircraft. Information on the character of the enemy transmissions could, however, readily be obtained.

Analysis of Operators' Logs

Each A.B.C. operator logged the frequency of signals received, the time of receipt and any words, letters, numerals or morse which he could distinguish. In order to obtain full information, the observations of the several operators for the same time and frequency had to be correlated. This analysis became a routine O.R.S. commitment which grew as the number of A.B.C. aircraft operating on one night increased from 11 on the first operation to over 25 in the summer of 1944. Each observation was plotted graphically in relation to time, frequency and believed nature of the traffic. Observations of the same line of traffic by different aircraft were thus grouped together. The calibration of the different receivers was frequently inconsistent, but it was usually possible to allow for this by corrections based on the frequency recorded for some transmissions which

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had evidently been heard by all the operators. Ground Cigar could sometimes be used as such a standard. When the grouping was complete it was possible to produce a log of the frequencies in use, the type of traffic used on each and scraps of the actual traffic. It was the primary duty of the operators to prevent messages being passed and the fragments they recorded were never in themselves sufficient to enable a picture of the enemy directions to be built up. However, the analyses prepared were welcomed by A.I.4, the Intelligence branch controlling the 'Y' service, and by No. 100 Group who could consider them together with the information gained from other sources.

T.R.E. was also supplied with copies of the analyses of the operators' logs. That establishment was concerned with maintaining the technical efficiency of A.B.C. and, when an increasing proportion of the traffic appeared to relate to the Benito method of fighter control, was able to suggest a modification to the A.B.C. transmitters which might cause increased embarrassment to the Benito controllers.

O.R.S. maintained liaison with the A.B.C. operators by occasional visits to the squadron and on matters not affecting the technical performance of the sets, was able to act as consultant. Thus, abnormal signals, e.g. speech interspersed in an apparent musical programme and speech breaking through suddenly in interruption of an unknown jamming type of signal, were discussed. Many such signals were probably attempts by the enemy to evade the attention of A.B.C. jamming. The detection of such attempts and the maintenance of the interest of the operators in anything they heard helped to develop maximum efficiency.

The analysis of logs was carried on until the end of September 1944 when the decline in need for the scraps of information it provided, then likely to be made more meagre still by the introduction of an additional V.H.F. jammer, Jostle, rendered the considerable effort involved in analysis no longer worthwhile.

<u>Losses of A.B.C. Aircraft</u>

The use of airborne transmitters was always accompanied by a proper anxiety that the enemy would in due course attempt to home on to the transmission. Therefore, the casualty rate of A.B.C. aircraft was always observed carefully. Since only one squadron was equipped with A.B.C., and since the whole squadron was for a long period completely equipped, there was no standard of comparison which took

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into account any influence on casualties which might be peculiar to the squadron. This difficulty was aggravated during 1944 when a special type of rear turret, the Rose turret, was introduced into No. 101 Squadron and, for some time, into no other squadron.

A running record of casualties of A.B.C. aircraft was maintained with the record of Lancasters of the same Group (No. 1 Group) as a standard. This showed over a long period no significant effect of A.B.C. on the aircraft carrying it. The question was investigated very thoroughly at the end of 1944, when it was desired to attempt a separate assessment of the value of the Rose turret which had been used by the Squadron in increasing numbers for the previous eight months.(1) This investigation revealed a curious temporary rise in the percentage of A.B.C. carrying sorties missing or attacked by fighters during a period early in 1944. During this period the enemy fighters had been making their main fighter effort over the target area, and in consequence there was a tendency for losses on any one raid to be more severe for aircraft bombing in any one height band or during a particular period of the raid. An attempt was made, therefore, to account for the higher A.B.C. aircraft losses on the grounds of their divergence in bombing height or time from the remainder of their Group. The bombing heights were not found to differ from the No. 1 Group practice, but the A.B.C. aircraft were of course spread throughout the attack, whereas the remainder of No. 1 Group was allotted specific periods. It thus appeared possible that the A.B.C. losses were a result of the special timing, but a convincing case could not be made out from the details available. Apart from this brief period of higher losses there was no evidence to show that A.B.C. had any effect on the risk of aircraft carrying it.

Tail Warning Devices

Brief History

It was always appreciated that in night operations whatever measures might be taken for the protection of the bomber force as a whole, each aircraft had to fight its own battles. Therefore, means to help the individual aircrew to combat the enemy defences were desirable. One advantage which the defences might hope to have was surprise. The course of a bomber might be plotted on the ground for the benefit of anti-aircraft guns or a fighter might approach using all the help to concealment that visibility conditions and the relative sizes of fighter and

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(1) 'The Operational Record of the Rose Turret to December 1944.' Bomber Command O.R.S. Report No. S.210. (A.H.B./IIH/241/22/14).

bomber allowed, and the bomber crew might know nothing until they were fired on or even hit. Much effort was expended therefore on attempts to provide the bomber crews with means to warn them of hostile activity, means which became known collectively as 'tail warning devices'.

The first such device, introduced on a small scale experimentally in November 1942, was Boozer. This was a receiver designed to pick up signals from enemy radar and to warn the bomber crew that the enemy was taking an interest in the movements of their aircraft. After a period of development, increasing numbers of Boozer sets were introduced into service until the device was finally withdrawn in September 1944 owing to changes in the enemy radar systems.

In June 1943, a tail warning device in the form of a complete airborne radar installation was introduced as Monica. This device was intended to provide to the bomber crew an audible warning when another aircraft came within the volume to the rear of their own aircraft where the presence of an unsuspected enemy fighter was an immediate menace to their safety. From October 1943 onwards increasing numbers of the Monica sets were modified by the substitution of a visual cathode-ray tube presentation of the position and range of aircraft astern for the initial aural warning. There was never sufficient of this equipment available to equip more than a proportion of the bomber force, and it was withdrawn completely in September 1944.

In November 1943 another warning device with a visual presentation of the position and range of aircraft in the hemisphere below the bomber was introduced. This was Fishpond, an attachment to the navigational aid H2S, which could therefore be fitted only in aircraft carrying that aid. It remained in service until the end of the European war.

Finally, in July 1944, small numbers of a new development of bomber radar, known as Village Inn or A.G.L.T. became available. This device was a complete centimetric radar installation which was capable not only of giving a warning of the approach of another aircraft but also of providing to the rear-gunner information sufficient for him to open fire at ranges beyond his vision. The device remained in service in comparatively small numbers until the end of the European war.

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At no time were sufficient quantities of the various tail-warning devices available to equip every bomber with even one of them. In this situation it was rarely that a bomber was fitted with more than one device and there were always some aircraft without any tail-warning aids. The devices in use at various periods were as follows.

November 1942 - June 1943		Boozer.
June 1943 - October 1943		Boozer and Aural Monica.
October 1943 - July 1944		Boozer, Aural Monica, Visual Monica and Fishpond.
July 1944 - September 1944		Boozer, Visual Monica, Fishpond and A.G.L.T.
September 1944 - May 1945		Fishpond and A.G.L.T.

<u>Methods of Assessing Results</u>

Since, after November 1942, there were usually some aircraft with and some aircraft without a tail-warning device on the same operation, an estimate of the effect on losses of any device could be attempted by comparison of the records of the two classes. Although it was possible that a tail aid would benefit the whole force by inducing the enemy to modify his interception methods in order to avoid detection, it was always expected that special benefits would be reaped by the actual users of the device.

The comparison of records of aircraft with and without a tail-warning was, however, not without difficulties. One of prime importance was the uncertainty of information about the identity of aircraft carrying the equipment. There were often several sources of this information, but only too often these disagreed and a large part of the labour in making analyses of the statistics was involved in endeavours to prepare reliable basic data.

From November 1943 onwards, the special equipment carried by an aircraft was required to be entered on the Raid Report prepared for each sortie after every operation, and from March 1944 data supplied were coded and punched on index cards of the Hollerith system. Analysis should, after this development, have been rapid and straightforward. In practice the reporting could never be relied on and laborious methods of checking had to be continued. Even when the basic data were obtained, other difficulties existed. Owing to the tendency, followed for reasons of training and servicing, to concentrate one type of equipment in one Group or even in a few squadrons, the effect of a special device could be obscured by the effects of tactics pursued by individual groups or squadrons. Then there were so many special equipments and aircraft modifications likely to influence losses.

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The result was that if the aircraft were devided into classes in pairs, the differentiation between each pair being the use of a tail-warning device, the numbers in each class were so small that no useful result could be obtained in a short period.

Apart from the fact that results were usually wanted quickly, there was an objection to making the comparison over a long period. If, during a period when a device was being fitted in increasing numbers, the loss rate of the whole force fell owing to the operation of factors other than the device, the association of the general decline in losses with the increased scale of fitting of the device would show fictitious effectiveness of the device in a comparison of percentage losses based on the trials of sorties for the period.

A method of overcoming many of the difficulties was worked out towards the end of 1943.(1) This method required the division of the data into categories within each of which the only important variable was the use made of the device of which the effectiveness was under consideration. Such a category would contain, for example, only Lancaster aircraft of No. 6 Group operating on one target and one night, similarly equipped and modified but only a proportion carrying a tail-warning device. For a comparison of loss rates, a calculation was made for each category of the number of the aircraft carrying the device which would have been missing if their loss rate were the same as that of the average for the category, i.e. the number which would be 'expected' as missing on the hypothesis that the device was without effect on the missing rate. The comparison of the totals of these values of 'expected' missing for the various categories with the totals of actual missing for the aircraft carrying the device provided an indication of the effect of the device. Normal statistical methods for testing the significance of the result were used.

From December 1943 onwards, this method was always applied in attempts to assess the value of tail-warning devices. Previous to that time the comparisons were based on straight percentage losses of categories of aircraft chosen, as far as the available data would allow, to avoid the complications of extraneous factors. It thus happened that the new method was available for treatment of Fishpond, Visual Monica, and the later experience with Boozer, but earlier Boozer and aural Monica results were interpreted by the cruder less trustworthy method.

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(1) Later published as O.R.S. Report No.113 - 'Note on the Comparison of Loss Rates' (A.H.B./II/39/1).

/ Estimation

Estimation of the effect of a tail-warning device on the number of attacks made by enemy fighters on bombers which succeeded in returning was also of importance. If the device was successful the bombers should be enabled to take action to reduce the number of occasions on which an approaching fighter reached a favourable attacking position. This might either reduce the total number of attacks made or thereby reduce both losses and the number of attacks reported by returning aircraft, or might by reducing the effectiveness of the attacks made increase the number of attacks reported but reduce the losses. An increase in the number of attacks without a reduction in losses might be produced if the enemy were homing on to the transmissions of the warning device. The results, obtained in precisely the same way as those concerning losses, required careful judgment in their interpretation.

It was clear that some indication of the value of a tail-warning device should be available in the reports of aircrews. If they were saved by it they would return and say so and a proportion of the others who were surprised and attacked in spite of their warning device would be able to report on the failure. Therefore, for each warning device a special report form was devised to extract from each crew on their return from an operation, information on the working of the device and the action they took as a result.

When a new device was introduced an O.R.S. representative visited the squadrons concerned and obtained as much information as possible by interrogation of the crews. The experience gained in this way provided useful information directly, and in addition gave assistance in devising and introducing to the squadrons a pro forma suitable for the device concerned.

Boozer

Exploratory Work

In September 1942 T.R.E. suggested that a simple receiver could be built which, installed in a bomber aircraft, could give to the crew a warning when they were under observation by enemy radar. The subject was discussed by the Signals and O.R.S. branches with T.R.E. and on 12 September O.R.S. recommended to the Air Staff that six of the suggested sets be prepared for a trial. It was suggested that the sets could serve as an investigation device, e.g. to determine when the enemy searchlights were radar-controlled, and might also serve as a warning device which would enable crews to take timely evasive action.

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The six sets asked for were produced rapidly and were available for operations in November. The code name Boozer was given to the device. The sets were fitted into aircraft of No. 7 Squadron, and an O.R.S. representative was stationed with the squadron to brief and interrogate the crews and to make an analysis of the results obtained.

The set was designed to provide an indication when the aircraft carrying it was in the beam of a Wurzburg by means of the illumination of a red light placed in the wireless operator's position. A pro forma was devised for the presentation of the information which the wireless operator was asked to log during an operation. After each operation, the track of each aircraft carrying Boozer was plotted from the navigator's log and the positions of incidents relating to Boozer as recorded by the wireless operator were marked on the plot. It was hoped by this means to obtain some idea of the reliability of Boozer for its designed purposes, and ultimately to gain information about the enemy's procedure in radar control.

After Boozer had been used on six major operations the results obtained were surveyed.(1) Five of the operations considered had been directed against Italian targets, and the defensive activity encountered was insufficient to permit an assessment of the value of Boozer as a warning device. It was evident, however, that the light could remain on for many minutes without signs of defensive activity becoming apparent, and this was thought to indicate that the sensitivity of the sets was too high. It was recommended that more Boozer sets be produced, and that an experimental reduction in sensitivity should be carried out.

Within a few days of the issue of this report, good evidence was obtained in an investigatory flight of the existence of an enemy A.I. operating on 490 mc/s. In the Command letter to Air Ministry asking for the increased number of Boozer which the Report had recommended, a request was made for the design of a Boozer which gave an indication of pick-up by an A.I. beam additional to the warning resulting from pick-up by a Würzburg.

T.R.E. set to work on the design for an A.I. Boozer, and at the same time produced an improvement in the Wurzburg Boozer. They found it to be possible to introduce discrimination between Giant Wurzburgs (used for G.C.I.) and Wurzburgs used for flak (G.L.) by making use of the differing pulse repetition frequencies of the two types of equipment.

(1) 'Preliminary Report on the Use of Boozer.' Bomber Command / Development O.R.S. Report No. S.72. (A.H.B./IIH/241/22/14).

Development of G.L./G.C.I. Boozer

In January and February 1943, eighteen sets which would discriminate between G.L. and G.C.I. were provided for Nos. 9 and 44 Squadrons, and six sets which had in addition to this facility the ability to indicate an A.I. holding, were sent to No. 7 Squadron. The Wurzburg sets were known as G.L./G.C.I. or Double Channel Boozers, and the Wurzburg/A.I. sets as Triple Channel Boozers. The arrangement for indication was to light a yellow lamp for A.I., a dim red one for G.C.I. and a bright red one for G.L.

The same close working with the squadrons and the same methods of analysis which had been developed for the initial Boozer were applied to the operational use of these improved sets, the pro forma for the recording of results being modified to include details of the types of radiation received.

A general summary of the experience obtained with the new sets was issued in March 1943.(1) The number of sorties flown with Boozer had not been large enough to reveal its efficiency in saving aircraft, but the record of observation was sufficiently complete to point the way for the further development of the device. It was shown that occasionally bright red indications (from the G.L. Würzburg) appeared to be useful in warning pilots to take evasive action, but that over heavily defended areas the number of warnings was far too great to permit action to be taken. The dim red indications of the Giant (G.C.I.) Würzburg had also been too numerous to be useful, the total duration of such warnings amounting to about 30 per cent of the time of flight along heavily defended routes. The brief experience which had by then been obtained suggested that yellow (A.I.) indications were not being received as frequently as had been expected, although it was possible to quote one incident when a warning had enabled a bomber to take action which may have prevented serious results from the fighter attack which followed.

Discussion of the results with T.R.E. had produced ideas for the improvement of the value of Boozer and it was therefore possible to indicate in the paper the lines of development which should be followed. These were:-

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(1) 'Report on the Operational Trials of Boozer'. Bomber Command O.R.S. Report No. S.86. (A.H.B./II/69/168).

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(a) Time delays should be introduced into the G.L. and G.C.I. Boozer circuits, together with a modification which would result in indications being given only when the aircraft was in the centre of the Wurzburg beam. It was hoped in this way to limit warnings to occasions when the aircraft was being plotted. The time delays suggested were five seconds for G.L. and three minutes for G.C.I., although it was suggested that those periods should be variable in order to permit adjustment as experience was gained.

(b) The sensitivity of the A.I. Boozer should be increased.

(c) In view of certain warning of danger expected to be provided by A.I. Boozer and the possibilities already demonstrated on operations, preference should be given in development and production to this unit.

These recommendations formed the basis of the Command's requirement for Boozer sent to Air Ministry on 3 April 1943. This requirement also included a statement of the range at which warning should be given by A.I. Boozer. This required range had been decided in discussions as varying from 10,000 to 3,000 feet, to be capable of adjustment as more experience with Boozer and knowledge of the enemy A.I. became available.

At about this time urgent consideration was being given to the introduction of another warning device into bombers. This, known as Monica, was a complete airborne radar set with transmitter and receiver designed to give an audible warning on the intercommunication system of the approach of aircraft from astern. It was generally considered to be more promising than Boozer but liable to have its life curtailed by enemy jamming. The prospective usefulness of Boozer had therefore to be considered in relation to that of Monica in urging production and fitting. The O.R.S. view in the spring of 1943 was that Boozer would form a useful follow-up to Monica when that device was jammed.(1)

Operational Trials of Improved G.L./G.C.I. Boozer

Double channel Boozer sets incorporating time-delay circuits and a modification (split discrimination) to limit indications to holding in the centre of the Wurzburg beam came into operational use during June 1943. The time delays were fixed at 5-10 seconds for G.L. and 25-35 seconds for G.C.I.

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(1) O.R.S. Report No. B.119. (A.H.B. Un-indexed).

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Detailed analysis of the observations made by the crews was again carried out by an O.R.S. observer at the squadrons concerned. It soon became apparent that a great improvement had been achieved and that the number of warnings had been reduced to a number which was small enough to permit action to be taken on any of them without introducing an appreciable risk of enemy defensive action appearing without warning. As Boozer continued to promise well, pressure on its development was increased, and at the end of August the Command requirement was laid down to Air Ministry as a Boozer for every heavy bomber.

A few sets with variable time delays were available in July, and experimental changes in the delay were made. An attempt was also made to determine the relative contributions of time delay and the split discriminations (introduced to confine warnings to holdings in the centre of the beam), by comparing the number of indications obtained with those obtained with the initial simple sets, with split discrimination and minimum time delays and with split discrimination and long time delays. It was shown that with a time delay of 30 seconds, 60 per cent of the dim-red (G.C.I.) indications had a duration of 40 seconds or less and were not associated with sighting of a fighter. Two of the ten indications lasting more than a minute were accompanied by fighter activity. The variable time delays were therefore set at one minute for G.C.I. with apparently satisfactory results.

The results obtained with double channel sets over a period of four months were reviewed,[(1)] and it was recommended that the time delays should be at one minute for G.C.I., at ten seconds for G.L. It was pointed out that some crew reports had associated accurate flak or searchlight activity with the dim indications which should warn only of G.C.I., and that therefore the possibility of changes in enemy practice which would affect the time delays required could not be ignored.

The effects obtained by the initiation of avoiding action on receipt of a warning were discussed, but insufficient evidence of successful action was available to permit formulation of firm recommendations. Operational conditions had been changed considerably since the first experiments with Boozer by the severe blow dealt to the enemy's use of <u>Wurzburgs</u> by the countermeasure Window.

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(1) 'Report on the Operational Trials of Modified G.L./G.C.I. Boozer.' Bomber Command O.R.S. Report No. S.107. (A.H.B./IIH/241/22/14).

It seemed that Giant Wurzburgs would now be used more for aircraft reporting than for G.C.I., and that flak would take on more frequently the form of a barrage. In these circumstances action taken on G.L./G.C.I. Boozer warnings would be of little value, but it was considered that stragglers could still be liable to engagement by radar controlled flak or fighters, and that therefore G.L./G.C.I. Boozer was a desirable fitting for all heavy bombers.

Development of A.I. Boozer

In accordance with the policy decided on after the initial operational trials, priority in production was given to A.I. Boozer. Simultaneously with the trials of modified G.L./G.C.I. Boozer described above, 200 sets of A.I. Boozer, the fruits of a crash production programme, were fitted into aircraft of Nos. 1, 3 and 8 Groups. Records of the indications and of the circumstances in which they were obtained were maintained and the number of sorties made by aircraft with the equipment was soon large enough to permit a comparison of their loss rates with those of other aircraft.

After some five weeks experience with A.I. Boozer it was apparent that although a few aircraft apparently obtained aid from a Boozer warning, a number of attacks by fighters without warning were still being reported. The total number of indications received was less than had been expected. Moreover, no effect of Boozer on the loss-rate could be detected.(1) The conclusion was reached that the range from the fighter at which Boozer was activated was too short. It was suggested that in the summer nights the range of visibility of a bomber was such that an overtaking fighter was able to dispense with A.I. before approaching sufficiently close to stimulate Boozer. It was also likely that some interceptions were being made by non-A.I. fighters under these conditions.

Discussions with T.R.E. on possible improvements resulted in two immediate possibilities; the widening of the frequency acceptance and a reduction in the minimum p.r.f. acceptance. It was felt that the reduction in p.r.f. acceptance might improve the performance of Boozer on the beams and quarters, since if the enemy transmission used split its effective p.r.f. at the bomber in approaches from beam or quarter would be reduced. Direct improvement of the range of Boozer could only be offered by the longer term project of incorporating a pulse

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(1) 'Report on the Operational Use of A.I. Boozer.' Bomber Command O.R.S. Report No. S.104. (A.H.B./II/69/168).

/ transformer

transformer in the sets. The two immediately possible modifications were put into effect in mid-July 1943, their introduction coinciding roughly with the first use of Window. The results obtained in the first five weeks experience with them were presented in the O.R.S. Report No. S.104 which, as mentioned above, dealt also with experience of the unmodified sets.

The results with modified sets were considered to show some promise. The numbers of sorties available for comparison of the missing rates of equipped aircraft with those of others were small, but a slight beneficial effect with Lancasters was established. Moreover, the percentage of sorties of Boozer aircraft on which fighter attacks were suffered was less than the corresponding percentage for other aircraft and, as none of the 12 fighters attacks reported by the Boozer carrying aircraft were made after Boozer warning, it appeared that Boozer was making possible the avoidance of an attack. The numbers being dealt with were of course too small to give real confidence that A.I. Boozer was useful, but the delays in production of radar equipment were such that it was necessary in this as in many other instances to take a decision based on judgment of the potential success of an equipment, provided that it functioned as it was designed to do, coupled with evidence gained in initial operations that it did in fact so function. Looked at in this way, A.I. Boozer appeared to hold good promise and it was concluded that fitting of the device should continue as rapidly as possible.

The investigation had shown that Stirling aircraft were reported as receiving Boozer indications far less frequently than were Lancasters, and that Boozer appeared to be having a bad rather than a good effect on the Stirling missing rate. Therefore, trials with a captured enemy A.I. were carried out by B.D.U. in order to compare the ranges of response of Boozer fitted in the Stirling and in the Lancasters. The results of these trials were presented at a meeting called by O.R.S. at Bomber Command on 19 October 1943, to which night fighter experts were invited. Meanwhile, it had been established that the small number of Boozer indications reported by Stirling squadrons had been due in part at least to incomplete reporting. It had also become apparent that A.I. Boozer was having no appreciable effect in reducing losses.

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The trials had revealed that with approaches made from level dead astern Boozer responded to the enemy A.I. at a maximum range of 1,200 metres, but that for other directions of approach when the A.I. beam was not pointed directly at the bomber the ranges obtained were much smaller. The view expressed by the night fighter experts was that such a performance would frequently permit the approach of an A.I. equipped fighter without warning on Boozer. Although it seemed possible that the maximum warning ranges obtained with the decaying enemy set used were less than they would be with a set in better condition, it was agreed that there was an urgent need for an all-round increase in Boozer sensitivity. The method of accomplishing this change had already been developed by T.R.E. - the incorporation of a pulse-transformer - but it was not until December 1944 that its application to operational sets began.

A.I. Boozer - Final Stages

The collection of statistics was continued and, in No. 1 Group, recording of the indications obtained and of observed enemy fighter activity was carried on. Owing to the increases in Boozer fitting and in O.R.S. commitments, it was not now possible to keep up the direct contact between the using squadrons and O.R.S. which had been established during the early stages of development. When the pulse-transformer modification, designed to increase sensitivity, had had about three months operational use, the statistics were again critically examined.(1) The loss record confirmed that until the modification was brought into use, no effect of Boozer could be perceived but gave very slight grounds for hope that the modified sets would produce a beneficial effect. An increase in the average duration of warnings which followed the modification was taken as evidence that sensitivity had been increased. With or without the modification, a high proportion (27 out of 34) fighter attacks had been made without an indication being seen on Boozer. The reported circumstances of the attacks were examined in detail and it was concluded that, although indications could not be expected for fighters not carrying an A.I. to which Boozer responded or for approaches from beam or bow, the performance of Boozer was still probably inadequate, especially for approaches from angles off dead astern.

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(1) 'The Operational Record of A.I. Boozer in No. 1 Group, November 1943 to March 1944'. Bomber Command O.R.S. Report No. S.151. (A.H.B./II/69/168).

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Had sufficient confidence been felt in the technical adequacy of Boozer, the device would at this stage have performed what had been originally foreseen as one of its important duties, that of providing information about the enemy equipment. As was revealed later, the enemy was re-equipping his night fighters with a new A.I., and it seems likely that many of the failures of Boozer to give warning are thereby accounted for. However, knowledge of the initial imperfections of Boozer influenced judgment and, although the device was still considered to be potentially most valuable, further trials with the old enemy A.I. were urged as a necessary step to its further improvement.

Both trials and the fitting of further quantities of Boozer sets were, however, long delayed, and the dwindling number of sets became insufficient to allow a proper appreciation of their usefulness. When, in July 1944, knowledge was gained that the enemy was using an A.I. on a frequency well outside the acceptance of Boozer, the use of A.I. Boozer as a means of obtaining information about the continued use of the old A.I. was suggested to the Signals branch. Indications were still being reported, the up-to-date statistics were quoted, and a proposed new pro forma designed to obtain the required information was presented. Then followed a period of indecision, finally resolved by information about the state of fitting of enemy A.I. obtained from sources more reliable than Boozer. The result was that in September 1944 Boozer was withdrawn from heavy bombers.

Although the further trials made with the old enemy A.I. against Boozer were carried out too late to be of immediate practical use, it is of some interest to note that they did justify the doubts which caused the request for them. The interpretation of the results was complicated by doubts about the efficiency of the A.I. as compared with one in newer condition, but there was little doubt that Boozer was not sufficiently sensitive. The view developed throughout all the O.R.S. reports that A.I. Boozer was a promising device which never fully realised its promise because of technical imperfection, was therefore probably justified.

G.L./G.C.I. Boozer - The Final Stages

Following the period of development described above, some models of G.L./.G.C.I. Boozer in its intended final form were brought into service during November 1943. The original system of logging particulars of indications received was continued, although the numbers involved were now too large to permit the regular plotting of the positions in which the warnings were received. An

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analysis of the records was made in February 1944.[(1)] As only one squadron was concerned, and a few sorties were flown by the squadron without Boozer, it was considered that no satisfactory estimate of the effect of the Boozer on losses could be formed.

Too many indications were received in the target area to allow any estimate of their significance to be made, and no recommendations for action there could be made. Eighty per cent of the dim (G.C.I.) indications and 70 per cent of the bright (G.L.) indications observed outside the target area were unaccompanied by visible signs of defence activity and only 2 of 276 dim indications were followed by sightings of fighters. No attacks by fighters followed Boozer warnings of Giant Wurzburg holdings, but eleven attacks were made without a Boozer indication. It was pointed out that the use of Window had so changed the use made of Wurzburgs that a dim indication should no longer be regarded as a warning of impending G.C.I. fighter attacks except in the case of aircraft straggling or engaged on small-scale operations. It was recommended, therefore, that aircraft in the main stream should take no action other than increasing vigilance on receipt of a dim warning. A cautionary note was, however, sounded as reports of accurate flak associated with dim warnings had been sufficiently persistent to warrant a suspicion of the use of flak control radar on a p.r.f. which resulted in a dim indication.

About 25 per cent of the bright indications received outside the target area had been associated with observations of flak, although only on a third of these occasions did the position of the bursts suggest that the fire was aimed at the aircraft receiving the warning. However, the total number of bright indications received outside the target area, an average of about one per sortie, was considered to be small enough to permit avoiding action to be taken at every bright indication. The duration of indications was considered in conjunction with the observations of defence activity in order to decide on the suitability of the time-delays used. In particular, the occasional association of accurate flak fire with dim warnings made it desirable to reduce the time-delay for such warnings if possible. No changes were recommended.

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(1) 'A Note on Operational Experience with the First Production Models of G.L./G.C.I. Boozer.' Bomber Command O.R.S. Report No. S.138. (A.H.B./II/69/168).

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A tactical instruction for the use of Boozer was issued by the Air Staff using as its basis the findings established in the O.R.S. report. Unfortunately, the extension of fitting of G.L./G.C.I. Boozer proceeded very slowly and little further useful information about its operational performance had been gained when it was decided to withdraw it from heavy aircraft in September 1944. This withdrawal was precipitated by the discovery mentioned above of the low prospects for future usefulness of A.I. Boozer owing to the change in the enemy A.I. The Boozer sets being produced were triple channel sets, and when the withdrawal of A.I. Boozer was decided upon, the retention of G.L./G.C.I. warning had also to be considered. As the use of Window had already been shown to have reduced the value of this part of the set, and as its continued fitting and servicing absorbed components and labour required for other purposes, a decision to withdraw it was taken.

Post Mortem on G.L./G.C.I. Boozer

When it became possible to test G.L./G.C.I. Boozer against captured Wurzburgs, it was found that owing to failure to allow for the effect of the rotation of the Wurzburg aerial on the effective p.r.f. no responses were obtained from Giant Wurzburgs and only dim responses were obtained from the small Wurzburg.(1) Clearly this cannot have been universally true since many bright signals were obtained, but it explained some of the puzzling operational experiences, such as the association of dim indications with flak, and showed why it had always been so difficult to analyse the results obtained.

Monica

Early Development

The successful use of airborne radar in night fighters turned thoughts at T.R.E. and elsewhere to the provision of radar detection devices in bombers. In July 1941, Bomber Command formulated a requirement for the design of such an equipment. The fundamental points of this were that the warning device should give warning of an approach of an aircraft when within 3,000 feet of the bomber by means of an aural warning over the intercommunication system, and should give an indication of the direction of the approaching aircraft. T.R.E. had already developed an apparatus which would meet this requirement, with the exception that

(1) T.R.E. Report No. 5/M97/MR/GEN.

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the direction of approach of the aircraft giving rise to the warning could not be indicated. At T.R.E.'s request O.R.S. discussed the possible modification of the requirement with the Air Staff at Bomber Command, and agreement was reached that an indication of range might be acceptable as a substitute for one of direction.

T.R.E. therefore proceeded to develop a modification of their device so that it would give its warning by a series of clicks in the intercommunication system of the aircraft, the recurrence frequency of the clicks varying with the ranges of the aircraft giving rise to the warning. The Air Fighting Committee agreed that the device so modified should be developed and demonstrated to the interested Commands. The demonstrations took place at the end of 1941, and the warning device to which the code name Monica had been given was accepted as a suitable one for all bomber aircraft. R.A.E. took over the development of Monica to the production stage in mid-1942, and by the beginning of 1943 its introduction into service could be contemplated.

Consideration of Introduction of Monica into Service

At the request of the A.O.C.-in-C., Bomber Command, in January 1943 O.R.S. gave consideration to the timing of the introduction of Monica into service.(1) It was expected that the enemy would jam Monica and Air Ministry's estimate of the useful life of the device was 3-6 months from the time of a set falling into enemy hands. An improved Monica incorporating anti-jamming features could not be expected in quantity for nine months, but there was a prospect that some sets of Boozer, a device giving warning in an aircraft held in an enemy radar beam, would be available before that time. Since all the bomber force could not be fitted simultaneously with the device it was necessary to estimate what sacrifices of the immediate saving of aircraft would be justified by the gains to be expected from withholding Monica from service until a larger proportion of the force could be fitted and an improved model was in better prospect.

Rates of effort and of losses based on past experience were assessed, and as a basis for argument it was taken that Monica would save half of that part of the bomber wastage caused by night fighters, then estimated as two-thirds of the total wastage. Considering these assumptions together with a forecast of the

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(1) O.R.S. Report B.119 - 'The Introduction of Monica in Bomber Cmd.' (A.H.B. Un-indexed).

/ rate

rate of fitting of Monica, it was estimated that the immediate use of Monica would save about nine aircraft by the end of February, but that the useful life would end in June. By delaying use until the end of February, these nine aircraft would not be saved, but the extension of life into the summer with a high proportion of aircraft fitted and with anticipation of increased fighter activity, was judged capable of saving 100 aircraft. It was recommended, therefore, that the introduction of Monica be delayed until the end of February 1943. However, the rate of fitting aircraft to take Monica, i.e. the installation of the aerial and the necessary racks to take the equipment, fell well below expectations and the situation was revised in conjunction with the Signals branch on 1 February, and again on 1 March, when postponement of introduction still appeared advisable.

Towards the end of March two other important factors arose. Firstly, it was likely that Monica radiations would interfere with an essential precision target marking device, Oboe Mark I; and secondly, there was a prospect of the use of Window, a powerful radio countermeasure against the enemy's night fighter control radar. It was argued that if Window could be used, the possible short life of Monica and the prospective time-gap before a replacement device appeared would be of much reduced importance, and immediate steps should be taken to derive benefit from the Monica sets held. It was considered, however, that if Window could not be used, the number of aircraft, estimated as 10 in April, which could be saved by the comparatively small numbers of Monica sets available would not justify their immediate introduction into service, and a postponement of introduction until 1 May would then be advisable. Permission to use Window was not given, and the introduction of Monica was, as recommended, postponed. The introduction did not in fact take place until mid-June 1943, a slight further delay being caused largely by the introduction of measures to reduce interference with Oboe.

Tactical Considerations

While preparations to introduce Monica into service were going on, flight trials with the device were being carried out at A.F.D.U. and at F.I.U. in order to establish a recommended course of action for a bomber on receipt of a warning. In addition, theoretical consideration of the problems involved was going on

/ within

within O.R.S. Calculations of the number of aircraft in the volume swept out by the cross-section of the Monica field of one aircraft relative to any other aircraft, gave the expected number of indications in terms of the mean concentration of aircraft in space, the mean relative speed of aircraft and the radius of the cross-section of the Monica field. The mean concentration and mean relative velocity were estimated from analysis of navigators' logs of operational flights. By this means it was computed that the average number of warnings received by one Monica in a raid by 400 aircraft on a target at a range of 300 miles would be 4·8.[1]

An alternative method of estimation was used, assuming that the airspeed of each aircraft remained approximately constant, and that the distribution of bombing times was Gaussian. These assumptions replaced the doubtful assumption made in the first method that the distribution of aircraft speeds at any time was the same at all parts of the bomber stream. The method used depended on the calculation of the probability that one aircraft would pass another, i.e. the probability that the distance travelled by one aircraft relative to another between target and base, is greater than the distance between them when one is at the target. The number of indications to be expected by one Monica in a raid of 400 aircraft on a target at 300 miles range, was estimated by this method as 3·3.

Taking into consideration both methods of estimation and their limitations, it was suggested that an average number of indications for operation would be five. At the end of May, it was suggested that owing to the increased size of the forces being sent, the figure should be raised to eight.

It appeared possible that the best action for a bomber to take on receipt of a Monica warning would be an orbit, and at the request of the Air Warfare Analysis Section (A.W.A.S.) O.R.S. produced in A.W.A. Paper No. 45 a mathematical treatment of the pursuit of an orbitting bomber by a fighter. O.R.S. interpretation of this calculation indicated that with Monica set up to give a maximum range of warning of 3,000 feet, the warning received might be just sufficient to allow an orbit to be used successfully as avoiding action.[2] The value of the orbit and

(1) O.R.S. Memo M.140 - 'The Expected Number of Indications on Monica from Friendly Aircraft'. (A.H.B. Un-indexed).

(2) O.R.S. Memo M. - 'The Orbit as evasive action with Monica'.

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R E S T R I C T E D

of the other tactics devised in the A.F.D.U. trials were discussed with the Air Staff, who finally issued a tactical instruction. This recommended that on dark nights bombers should, on receipt of a warning, alter course 45° and descend 500 feet in a shallow dive, and if the warning persisted should orbit. On a moonlight night visual search was recommended as the first action.

The Introduction of Monica into Service

Monica was first used on the night of 22 June 1943. In order that the investigation of its early history may be appreciated, it is desirable briefly to describe the characteristics of the equipment initially used.

The crew of a Monica carrying aircraft received warning of the entry of a second aircraft within an approximately hemispherical zone at their rear. The maximum range at which a warning could be given was 1,300 yards, and the minimum range within which there was no reaction was 200 yards. The set obtained responses from the ground and therefore could not be used at heights below about 4,000 feet. The warning was given by a high-pitched 'pips' in the intercommunication system, the frequency of the pips varying with the range of the source of the warning from about once per second at 1,000 yards to almost continuous note at 200 yards. The volume of the warning note could be controlled.

The maximum range was capable of adjustment on the ground with the aid of a special test set; for the initial operations it was to be set to 3,000 feet. The minimum range was dictated by the Suppression Control which had to be set in the air initially and checked periodically. Provision was made for testing the serviceability of the set by means of operation of a push-button switch.

Investigations of the Initial Performance of Monica

For the first few weeks an O.R.S. representative was stationed in No. 4 Group, the Group with the highest proportion of Monica fitted aircraft, in order to brief crews and to obtain details of their experiences. In addition, a pro forma was prepared in order to obtain for O.R.S. the experience of all Monica users. At the same time a record of the sorties made by and losses of Monica aircraft was maintained, and arrangements were made for an account of the use made of Monica to be included in the reports of encounters with enemy aircraft normally rendered.

/ Reports

Reports made in writing were not very satisfactory. As often happened crews who had difficulties became discouraged and discharged the irksome duty of reporting inadequately. Personal contacts, however, extracted much useful information about operational troubles. Some of these, e.g. the production of a howl on the intercommunication system, were referred to R.A.E. technical officers who were also closely interested; others could clearly be seen to be manipulation faults, and the crew concerned could be given immediate guidance. The O.R.S. officer stationed at No. 4 Group for the investigation, made a number of training flights and gained personal experience of some of the faults which was most useful in diagnosing some of the faults reported, and in developing a mutual understanding with the crews.

A frequent complaint of crews was that too many indications were received. Many of these complaints arose from incorrect setting of the Suppression Control which had to be checked in the air, and it was possible to improve the situation by encouraging the squadrons to improve the instruction of the wireless operators. Nevertheless, the numbers of genuine indications received gave rise to disquiet. The numbers were somewhat higher than forecasted, individual aircraft usually citing between 5 and 20, and they were found in practice to be too many to permit action on every warning. Apart from the strain directly imposed, some anxiety was felt by crews about the increase in risk of collision involved in frequent avoiding action. It seemed inevitable that such a situation must lead to all warnings being ignored, and in fact information was gained that sets were being switched off. Horeover, no effect of Monica on the loss rate of aircraft carrying it could be detected.

The maximum range was reduced to 800 yards as an immediate measure. Further modifications suggested by O.R.S. were to reduce the range of Monica above the level of the bomber, and to confine the warning to the rear gunner.[1] These suggestions were referred to R.A.E. for technical consideration, but in due course were found to involve such difficulties in modification that they were abandoned.

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(1) Bomber Cmd Countermeasures Cttee Meeting Minutes 26 June 1943.

/ Further

Further discussions at Headquarters went on as further reports came in, and on 13 July a revised tactical instruction was issued. This laid down that the maximum range to be used for Monica, and the part of the route along which the device was to be used, were left to the discretion of squadron commanders. The advice was given that the range should be varied according to conditions of operation so that the number of indications from friendly sources was reduced to a minimum consistent with a warning being given at ranges beyond which a fighter would have little chance of opening fire with success. The maximum range suggested for a concentrated raid on a dark night was 400 or 600 yards, and for a moonlight night 1,000 yards.

There was very little enthusiasm among the crews for reducing the maximum range; it was generally held that a warning at a range less than 1,000 yards would come too late. There was therefore something of an impasse, and on 22 July the case for a reduction in range was expounded to a conference of No. 4 Group squadron commanders by representatives of O.R.S. and of the Command Air Staff. It was made clear that the ranges at which a fighter could be identified visually were usually so short that a radar warning on which immediate avoiding action could be taken was most desirable. Owing to dilution of warnings from fighters by warnings from friendly bombers, such action could only be taken with Monica if its maximum range was shortened. The arguments were convincing, and all No. 4 Group squadrons reduced the maximum range of their sets to 600 yards. The squadron commanders of No. 6 Group were not so easily convinced in this way and retained independent action.

The effects of the reduction in range in No. 4 Group were carefully watched. There was a reduction in the number of indications received to an average of about four per aircraft per operation. This seemed to be a not unreasonable number for action to be taken on each warning, but crews were still reluctant to take immediate action. An important influence on their attitude was their fear that every additional manoeuvre increased the risk of collision with other aircraft.

The question of increase in the collision risk associated with the performance of a diving turn when indications were received on Monica was considered theoretically.(1) The variations in risk for different values of the

(1) O.R.S. Memo M.80 - 'The Effect of a Diving Turn on Collision Risk'. (A.H.B./II/241/22/3).

/ speeds

speeds of aircraft of the radius of the turn made, and the maximum range on Monica, were calculated for the case of a dive at angle of 10° and an angle of bank of 60°, and a case where from the degree of bank the collision risk was judged to be a maximum. The investigation showed that in the least favourable circumstances the increase in risk of collision was 50 per cent. In view of the small number of losses then attributed to collision, such an increase seemed to be much less than the gain hoped for in a full use of Monica. The result was not communicated to aircrews as they did not all share the view that losses to collision were negligible, but it was helpful in reassuring the Air Staff and O.R.S. that the recommendations made for the use of Monica were not introducing a large new hazard.

The Effect of Monica I on Aircraft Losses

The estimation of the effect of Monica on losses was being complicated. Another warning set, Boozer, designed to give warning of an enemy radar beam holding the aircraft was being introduced, and the tendency to fit the aircraft of one Group wholly with one or other of the warning devices was making difficult the ideal comparison - aircraft equipped with one device compared with aircraft of the same type and Group having no warning equipment. The introduction of Window on 24/25 July, with an obvious immediate effect on overall losses, also ruined comparison of present with past experience. Such comparisons as could be made consistently failed to reveal any benefit arising from the use of Monica. The position was reviewed early in August.[(1)] It was pointed out that warning was not being received of about 25 per cent of the approaches of enemy aircraft for which details of the Monica reaction were known. These failures, attributed to possible gaps in the coverage and to poor serviceability were suggested as a possible pointer to the cause of the lack of effect on the loss figures, on the grounds that a false reliance on the radar warning might be causing relaxation of the gunners' vigilance. Further suggestions, advanced tentatively, were that the enemy was using the Monica transmission to assist his fighters, and that some aircraft were being destroyed owing to loss of control during evasive action. It was not, however, possible to suggest measures which would make the existing Monica a better instrument other than that the serviceability must be improved.

(1) O.R.S. Memo M.76 - 'The Operational Use of Monica.' (A.H.B. Un-indexed).

/ By

By the end of August no signs of improvement in the record of Monica could be detected, and on 27 August what had become generally recognised in the Command as the failure of Monica was discussed at Air Ministry. It was decided that efforts to improve Monica in its existing form should go on, but that at the same time a vigorous attempt to develop a version with a visual presentation of the warning should be made.

The efforts to improve the serviceability of Monica had some success, but no evidence could be found that the device was saving aircraft. A careful examination of the data relating to the effect on losses of Monica and Boozer was made during September. There was then no satisfactory basis for a direct appreciation of Monica by comparison by classes of aircraft differing mainly in whether or not they carried the device. It was, however, possible to compare certain classes of Monica carrying aircraft with corresponding classes of Boozer carrying aircraft, and another class of Boozer aircraft with aircraft without a warning device. The melancholy result was that, although Boozer aircraft had a lower loss rate than Monica aircraft over the period considered, Boozer appeared to provide no appreciable benefit.(1) This conclusion could only be a suspicion that Monica, so far from being a benefit was doing harm, and the possibility of enemy fighters homing on to Monica could not be disregarded.

Further analyses of the loss figures after more operations failed, however, to show that Monica was affecting the scale of losses in either direction.(2) Thereafter, the increase in bomber concentration which was brought about as a tactical countermeasure against changed enemy fighter defence methods, appeared to make the case of Monica with aural presentation hopeless, and although its use continued to some extent little further interest was taken in it outside the few squadrons who remained hopeful. Moreover, the development of a Monica with visual presentation was giving a renewed promise of a successful tail-warning system.

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(1) O.R.S. Memo M.77 - 'A Comparison of Monica and Boozer Equipped Aircraft, 24/25 July 1943 to 6/7 September 1943'. (A.H.B. Un-indexed).

(2) A survey for September - November is contained in O.R.S. Memo M. - 'A Note on the Loss Rate of Aircraft fitted with Aural Monica'.

/ Visual

Visual Monica

The modification of Monica to produce a visual indication proceeded rapidly as a result of collaboration between T.R.E., R.A.E. and Radar officers of No. 5 Group, and by the end of October No. 5 Group had a squadron fitted with the modified sets. The indicator provided a measure of range of the source of a warning and a rough estimate of D/F in azimuth. With this presentation there was no need to restrict maximum range, since the contacts obtained at long ranges could be ignored and the provision of D/F put the taking of avoiding action on to a sounder basis. There was therefore a renewal of hope in Monica. The drawbacks were that the set had to be watched, a task allotted to the wireless operator, and that the components necessary to modify the existing Monica sets were in short supply. The modified set received the name of Monica III or Visual Monica; Monica II had been a development projected on a new radio frequency, but abandoned as another form of tail-warning device, Fishpond, (described below), was becoming available.

Operational trials were carried out in No. 5 Group and were already watched by the O.R.S. representative in the Group who, by means of a pro forma, secured very complete information about the observations made during every sortie. Apart from initial serviceability troubles, ascribed to the inexperience of the operators, Monica III seemed to be a most promising device and in so far as the small numbers involved permitted an assessment, appeared to be saving aircraft.

Extension of fitting therefore proceeded as far as the supply of the necessary components permitted. In order to obtain information on performance of the sets a new pro forma was prepared for the use of all Groups. After some information had been gained from the use of this pro forma, a draft tactical instruction was prepared, in January 1945. This, after describing the indications received and the limitations of the apparatus, made suggestions of manoeuvres which would help to obtain some idea of the elevation of an aircraft giving a response, of guides to the identification of responses from hostile aircraft, and finally suggested a suitable crew drill and patter. It was made clear that the value of Monica was to enable defensive action to be taken on a radar contact without waiting to see the enemy fighter, and that a combat manoeuvre, normally a corkscrew, should be commenced whenever a contact whose identity was in doubt closed in to 6-800 yards.

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The Air Staff was not prepared to issue an official tactical instruction, but the draft was taken to the squadrons then equipping with Visual Monica by an O.R.S. officer for discussion.

Operational Results with Visual Monica

Simultaneously with the fitting of Monica III, another tail-warning device with a visual presentation was being introduced into service. This was Fishpond, an attachment to the centimetric navigational aid H2S, which provided indications of the presence of aircraft in a hemisphere below the fitted bomber. The limited amount of equipment available gave no immediate opportunity of a choice between Monica and Fishpond, but since guidance was required for future planning the consideration of the equipments was usually made on a comparative basis.

Operational experience soon confirmed that, as had been anticipated, the failure to distinguish between friendly and hostile contacts was a serious handicap to both Fishpond and Visual Monica. A proposal was made that an infra-red signalling system which was projected for another purpose should be adapted for use in identification with the tail-warning devices. The details of this scheme, which was discarded after trials, are presented in the section dealing with Fishpond.

At the end of February 1944 a detailed analysis was made of the performance of the two tail-warning devices.[1] The data derived from the special questionnaires returned for every sortie, and the accounts of combats with enemy fighters, were examined in order to provide information on the loss statistics, the success and failure in giving warning before combats and serviceability. The proportions of sorties becoming missing or attacked (fired on) by enemy fighters had been consistently lower for bombers equipped with Monica III than they had been for otherwise comparable bombers without a tail-warning device. This conclusion could not be shaken by more rigorous analysis of the results, and it was inferred that Monica was frequently allowing action to be taken which prevented an approaching fighter from reaching a firing position.

(1) 'The Operational Performance of Fishpond and Monica III, October 1943 to February 1944.' Bomber Command O.R.S. Report No. S.133. (A.H.B./IIH/241/22/14).

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At the same time it was shown that a considerable proportion of combats (20 out of 57) occurred without prior warning of the fighter's approach being received. The reasons for these failures were examined and it was shown that most of them could be accounted for either by unserviceability or by the engagement of the wireless operator, whose responsibility it was to watch the set, with other duties. Comparison of the reports of unserviceability made on the operational questionnaires with the reports of technical unserviceability made by the Radar branch, suggested that some of the troubles were caused by faulty manipulation. It seemed likely, therefore, that many of the failures to provide warning were a result of inadequate training in the use of the device, an impression which had also been gained in interrogation of crews. A strong plea was made, therefore, for the provision of better facilities for training including the development of a special ground trainer and a maximum of air training with fighter affiliation.

With regard to the relative merits of Monica and Fishpond, the statistics of losses did not show either to be conclusively superior, and an opinion had to be based on performance in combat. In this respect Fishpond had appeared to be somewhat inferior, largely by reason of its dependence on H2S and its lack of cover above the horizon. However, Monica was thought more likely to be jammed or used as a target for a homing device. The fall in losses and attacks on Monica equipped aircraft was taken as evidence that homing was not yet a danger and jamming had also not been reported. The further development of Monica was therefore preferred in preference to Fishpond.

The report was regarded as encouraging by those concerned with the performance of tail-warning devices, and was circulated to Groups by the Radar section of the Signals branch with a particular direction to its recommendations for intensified training. Means of expanding the production of Visual Monica were explored and several variants of the device appeared, differing in the components employed to secure the visual presentation. Further results were, however, disappointing. During May and June the proportions of Monica equipped aircraft missing or reported as attacked by fighters were similar to those for otherwise comparable aircraft without a tail-warning device. Moreover, the number of fighter attacks made without a Monica warning was disconcertingly large. Analysis of the causes of these failures confirmed the results previously found, that unserviceability and inability of the wireless operator to maintain a continuous watch on the set were major deficiencies.

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In an attempt to assess the effects of experience with Monica, arrangements had been made to separate the statistics relating to wireless operators with less than four operations with Monica from the remainder. The results obtained were inconclusive, but it was always arguable that operational experience without adequate basic training was of little value, and the idea remained that better training was the stimulus which would make Visual Monica fulfil its early promise. It was known that lack of equipment and the increased intensity of operations were limiting training. Early in May, the Training branch at Bomber Command had set up a permanent committee on which O.R.S. was represented, to consider training in the use of radar devices. This committee was able to decide what steps ought to be taken but was unable to accelerate them.

In June, an O.R.S. officer was sent to squadrons in No. 5 Group in order to discuss with the crews their difficulties in using Monica and to explore the possibilities of improved training. The training history of a sample of wireless operators was investigated. It appeared that, although great efforts were being made in instruction on the ground, the classes were usually much too large for satisfactory efficiency and instruction in the air was inadequate. It was concluded that, with the existing operational commitments, only the arrangement of training with Monica, including fighter affiliation exercises, in Heavy Conversion Units would give good hope of obtaining benefit from the device. In addition, the opinion already formed from written reports that the wireless operator was not able to give sufficient attention to Monica on operations, was confirmed by personal enquiries. It was concluded that if an extra member of the crew could not be provided then a member of the crew other than the wireless operator should be enabled to see the Monica tube or a repeat indicator.

These considerations were discussed,[(1)] but no action was taken because direct evidence was obtained of the existence of a handicap to Monica potentially much greater than inadequate training - an enemy device for homing on to Monica transmissions.

The Homing Danger

The statistics of losses and fighter attacks had not provided any suggestion that Monica carrying aircraft were being selected for special attention, although the possibility of the enemy using a homer had been in mind throughout the history of the device. Then, in July 1944, there fell into British hands an intact specimen of a German equipment, the Flensburg apparatus, which was clearly designed to home on to it.

(1) O.R.S. Memo M.75 - 'The Training of Wireless Operators in the Use of Monica'. (A.H.B. Un-indexed).

It had become known previously that the enemy was making use of radiations from bombers in order to plot their course. The risks arising from this activity over enemy territory were at that time accepted since, if the bomber crews were denied the use of their radiating devices the enemy could turn readily to alternative methods of plotting. The proven existence of the airborne homer, Flensburg, and the strongly suspected existence of another one for use against the centimetric navigational aid H2S, Naxos, made reconsideration of the position imperative.

The various questions involved were discussed at length between O.R.S. and the Signals branch. The first obvious step, trials of the captured Flensburg against Monica aircraft, were organised without delay. Other results of the O.R.S. Signals discussions were presented in a joint memorandum prepared for the Air Staff.(1)

In this memorandum it was argued that the statistics of losses of fighter attacks on Monica equipped aircraft indicated that homing on to individual aircraft had probably not been practised, but it was considered likely that homing on to the bomber stream with Flensburg had been followed by the use of the A.I. S.N.2 to follow individual targets. Since a Window counter to the S.N.2 had just been introduced, the use of Flensburg against individual aircraft was visualised as a probable development. It was clear that the use of Monica by a small proportion of the force endangered the whole force, a high proportion of which had not the compensating advantage of a tail-warning device, and that therefore the forces used should either be equipped completely with Monica in order that all should have the benefit of a tail-warning, or that Monica should be withdrawn completely. The problem was one which the known facts could not be used to solve, since the relative advantages to individual aircraft of a tail-warning vis-a-vis homing were uncertain. It was suggested, therefore, that if the statistics for the month of July failed to reveal a lower loss rate for Monica equipped aircraft, the Monica sets should either be segregated in one Group which would be routed independently of the remainder of the Command, or that the Monica fitted aircraft should in their existing Groups be sent on a separate route. This project was considered to be likely to show whether Monica could hold its own against the

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(1) 'Appreciation of the Use made by the Enemy of Transmissions from our Bombers.' [redacted] Bomber Command O.R.S. Report No. B.218. (A.H.B./IIH/241/22/12).

/ homer

homer, and at the same time to free aircraft without a tail-warning device from the attentions of Flensburg equipped fighters. It was considered that the July figures alone might show that individual homing was being successfully practised and that, if this proved to be true, then the use of Monica should cease.

Homing Trials with Flensburg

By the time that the July results became available it had been established experimentally that Flensburg could be used to home on to a stream containing Monica from a range of over 50 miles, and that homing on to individual aircraft was possible. Therefore, although the July statistics showed a slight balance in favour of Monica, opinion which had been changing almost daily in the discussions between O.R.S. and Signals branch hardened against Monica. A new appreciation was made on 11 August, and it was recommended to the Air Staff that the use of Monica in its existing form be withdrawn, pending a large scale trial of Flensburg against bombers equipped with Monica sets modified to increase the difficulty of homing.

The Air Staff agreed that a trial should take place, although the use of Monica was retained. Details of the trial were worked out by the Signals branch and O.R.S. in consultation with T.R.E. and the interpretation of the results obtained was delegated to O.R.S.

The plan was that 100 bombers would fly at heights between 15,000 and 18,000 feet at a speed of as near 160 RAS as practicable on the route Cambridge, Gloucester, Hereford, Cambridge. All of them were to be equipped with Monica sets set up in the frequency range 223 $\pm$ 1 mc/s, and to have their pulse repetition frequencies sweeping in the range 60-300 pulses per second. These adjustments were intended to make the task of homing on to individual aircraft as difficult as was possible without major modifications to the sets. As the bombers left Cambridge on the first leg, the fighter (a Ju.88) equipped with Flensburg was to attempt to home into the stream from a position in the Reading area and, having reached the stream, was to attempt to home on to individual targets. The plan was carefully worked out to ensure that the distances selected would permit homing to the stream on a curve of pursuit in time to allow plenty of time for the trials of individual homing. The return stage of the flight was to be reserved for trials of Window against S.N.2 and it is dealt with in the section of this work dealing with that countermeasure.

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In order to permit assessment of the concentration of aircraft, arrangements were made for photographing the P.P.I. tubes of a G.C.I. station and of an A.M.E.S. Type 11 station which would observe the bombers along a part of their route, and crews were instructed to record the time and height at which their aircraft reached the turning points. Crews were also asked to log periodically the number of contacts shown on Monica at ranges up to 3,000 yards. In addition, the Monica signals were to be monitored on the ground to check the setting up of the frequency and p.r.f. The flight was made by 71 Lancasters on 30 August 1944, and an analysis of the results was presented on 5 September.(1)

The effect of Window on the P.P.I. tubes of the ground equipments at the time when photographs were taken, prevented a count of the true aircraft responses (unfortunately some crews discharged Window during the part of the trial selected for the Flensburg operation). The photographs were judged, however, to permit a reasonable estimate of the width of the bomber stream, and the recorded times at turning points allowed an assessment to be made of the length of the stream and of the distribution of aircraft along it at various stages of the flight.

The average concentration of bombers during the Flensburg trial was about 0·9 aircraft per cubic mile. This was somewhat greater than that realised on most night operations, a fact expected to make homing on to individual aircraft more difficult. The courses of fighter and bomber were plotted, and the results of the report of the radar operator in the fighter could readily be interpreted. It was clear that the fighter was able to begin homing from a range of 45 miles when approaching the bombers head on, and that no difficulty at all was experienced in homing into the stream. After the fighter had been brought into the stream, two successful interceptions of single aircraft were made within 25 minutes using Flensburg as the sole aid.

The results were therefore that Flensburg enabled a fighter to home from a considerable distance on to a bomber stream even under the most difficult conditions of a head-on approach, and permitted the selection of individual targets in circumstances which had been made as difficult as possible by adjustment of the frequencies and p.r.fs of the Monica sets. (Although ground

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(1) O.R.S. Report No. S.175 - 'Trials of Flensburg and S.N.2 against a Bomber Stream'. (A.H.B./IIH/258/1/80).

/ monitoring

monitoring during the flight showed that the adjustments made were not as recommended, it was felt that they approached the recommended scheme as well as the available test gear and labour would permit in operational conditions). In addition, the second part of the trial had demonstrated that the enemy's other main means of intercepting individual bombers in the stream, the S.N.2 could be defeated by the use of Window. The only alleviating factor in this strong case against Monica was that the Flensburg had been used by a most skilful operator, but, in judging the issue, it was considered likely that the bulk of the enemy's successes were gained by a few of the best operators.

The potential dangers of Flensburg thus appeared to be so great, and the possible savings by the use of Monica as judged by past experience appeared to be so small, that the immediate withdrawal of Monica was recommended. This recommendation was accepted. The withdrawal coincided with a considerable advance on the Continent by the ground forces which produced effects too large to allow any result of the end of Monica to be perceived. However, captured German fighter crews supplied information which indicated that the loss of the Flensburg homing facility at a time when other means of fighter guidance were falling into confusion was one of the factors which helped to destroy the effectiveness of the night fighter force.

Fishpond

Development

The navigational aid H2S is a radar set working on centimetric wavelengths which scans the ground. The reflections produce signals on a P.P.I. tube which allow features on the ground which differ considerably from one another in their reflecting ability to be recognised. As no reflection can be received from the ground at a range shorter than the aircraft's vertical distance above ground, the centre of the P.P.I. picture is a ring of radius corresponding to that distance in which no ground returns appear. However, a second aircraft flying somewhere between the H2S set and the ground which it is scanning will reflect radiation and cause a signal to appear within the inner circle.

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The reproduction of the inner circle on a second P.P.I. with an expanded time-base gave rise to the tail-warning device known as Fishpond. As the H2S beam scans only below the aircraft, Fishpond was limited to the detection aircraft in a hemisphere below it, having a radius equal to its height above ground. There was of course a minimum range within which no echo from an aircraft could be distinguished because of suppression of the direct pulse. Provision was made for setting up marker rings on the P.P.I. at intervals corresponding to one mile slant range and for a line of flight marker. Since the Fishpond picture was essentially only a magnified part of the H2S picture it was affected by the controls of the H2S set and the simultaneous operation of both devices, although easily possible, required that consideration be given to both pictures with, in some circumstances, a compromise arrangement between them.

Following the development of the apparatus by T.R.E., arrangements were made for the crash production of a limited number of sets. Trials, carried out by B.D.U. in August 1943, gave promising results. The detection of aircraft in the hemisphere below the set was satisfactory and, although no distinction could be made between signals from friendly and hostile aircraft, Fishpond appeared much less likely to be embarrassed by friendly contacts than Monica which was at that time being used with an aural warning system. The minimum range at which an aircraft could be detected was, however, found to be inconveniently large with a value of about 400 yards.

In order to assist the Air Staff in the preparation of tactical instructions for use with Fishpond, O.R.S. gave consideration to the numbers of friendly contacts to be expected on an operation and to means whereby identification might be aided. The number of indications expected was estimated approximately by considering the Fishpond field as a vertical cylinder whose height was 0.77 times its radius, ~~cylinder of height equal to 0.77 x radius~~ [redacted] with the Fishpond at the centre of the top disc. The number of aircraft which would be contained in such a cylinder was calculated for various positions of the Fishpond in the bomber stream and for five values of the cylinder radius.(1) The distribution of aircraft at the target was taken as that indicated by the plot of night photographs and from the bombing heights logged by aircrews

(1) O.R.S. Memo M. 160 - 'The Expected Number of Fishpond Indications, 24 August 1943'.

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for typical raids. The distribution en route was based on the assumption that 95 per cent of the force flew in a lane of route 30 miles wide, and that the distribution across the lane was Gaussian. The number of contacts expected varied considerably with the height of flight and position in the stream considered. For a height of flight of 20,000 feet en route, the number of contacts expected within 3 miles was 10·7 per aircraft on track and 0·1 for aircraft 12 miles off track.

The tracks which could be traced out on the Fishpond tube by signals from aircraft overtaking in various ways were considered as a possible aid to identification. It was found that the tracks of aircraft overtaking the Fishpond carrying aircraft below it, and on a parallel course but outside the vertical plane containing the Fishpond, should have a characteristic form tending to move away from the centre of the tube as the two aircraft became beam to beam. A fighter might be expected to produce a track which curved into the centre. These details were discussed, but were not published; it was clear that the fair number of friendly contacts expected would make the plotting of every individual track a matter of some difficulty, and that operators would have to regard as suspicious any aircraft indicated as astern.

Another rather academic suggestion was a means of estimating the elevation of an aircraft giving rise to a Fishpond signal,[1] based on the change in apparent azimuth produced by a rapid bank by the Fishpond aircraft.

Operational Experience

Fishpond was introduced into the P.F.F. in October 1943, and the scale of fitting within that Group was rapidly extended during the following two months. The Radar section of the Signals branch took a keen interest in the device and carried out its own investigations into its operational usefulness. A pro forma to be completed for every operational sortie made with Fishpond was prepared jointly by the Radar section and by O.R.S. to provide the information required to meet the needs of both parties.

The completed operational returns were examined by the Radar section and independently by O.R.S. The Radar section concentrated on causes of unserviceability and operational difficulties, and on the extraction of reports of incidents which could be used to encourage interest in the device. Reports based

(1) O.R.S. Memo M. 161.

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on these considerations were circulated to the squadrons each month. O.R.S. gave more consideration to the long-term statistics and to the failures of Fishpond to give warning of a fighter's approach.

The Problem of Identification

The aircrews' reports soon showed, as had been expected, that a major difficulty in using Fishpond was the impossibility of making a distinction between responses received from bombers and those received from fighters. Operators were reporting about 12 contacts per operation on the average which had to be considered as possibly hostile. Rather more than 10 per cent of these contacts continued to be regarded as hostile, on the basis of their relative movement, until visual observation showed them to be friendly.

At this time urgent consideration was being given to the development of a system of identification for use with a blind-firing device, A.G.L.(T). This system involved fitting infra-red transmitters in the noses of all bombers. Since Fishpond gave an accurate bearing for any contact, it seemed possible that the rear gunners might identify friendly aircraft by means of an infra-red receiver when warned by the Fishpond operator of the direction of a contact. Therefore, after discussions with the experimental establishments on the technical aspects, a proposal was made to the Air Staff that B.D.U. should carry out flight trials of such a scheme.(1)

The proposals were agreed and some trials and a great deal of discussion followed. Finally, however, in May the Air Staff was advised to abandon the scheme since there seemed to be little hope of safeguards against the enemy's copying of the infra-red signal, and since the prospective rate of supply of infra-red receivers was so low that a change in the infra-red scheme as devised for A.G.L.(T) seemed likely to precede the fitting of all aircraft.

Analysis of Operational Records

At the time of introduction of Fishpond, another tail-warning device, Monica, was being modified in order to change the presentation of warnings from the original aural form to a visual indication on a cathode-ray tube. The limited amount of equipment available gave no immediate opportunity of a choice between Monica and Fishpond, but since guidance was required for future planning the two equipments were usually considered together.

(1) O.R.S. Memo M. - 'A Note on the Need for Means of Identifying Friendly Aircraft at night'.

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At the end of February 1944, the analysis made of the performance of the two devices was summed up.(1) The data derived from the special questionnaire returned for every sortie with either device and the accounts of combats with enemy fighters were the main source of information on the successes and failures of the devices in service. The questionnaires were considered together with raid reports and serviceability returns in order to obtain the most reliable statistics of casualties.

The record of Fishpond carrying aircraft was not consistently different from that of aircraft without a tail-warning device. For the P.P.F., considered separately because of its special operational function, the use of Fishpond appeared to be associated with a slightly higher loss-rate, but for Main Force aircraft the reverse effect was found. An attempt to discover a correlation between use of Fishpond and any special operational duty within the P.F.F. proved abortive. However, the lower loss-rate for Fishpond carrying aircraft in the Main Force was accompanied by a marked reduction in the number of fighter attacks reported by these aircraft. Although the numbers were small it appeared that there was a definite indication that Fishpond was permitting avoiding action to be taken in time to prevent some fighters reaching an attacking position. While the result obtained in the P.F.F. did not support this, the potentialities of the equipment were considered by both the Radar section and O.R.S. to be such that training in the use of the equipment should be improved, and the report emphasised the Main Force result in a manner not wholly consistent with an objective view of the whole matter.

Analysis of the performance of Fishpond in combats with fighters showed that only in 13 of 210 instances was a prior warning of the approach of the fighter received. Although some of the failures were due to approaches being made outside the cover of the warning device, the largest single cause was reported as unserviceability of equipment. There was no means of discovering how many of the forms of unserviceability arose, or how failures to receive warning on apparently serviceable equipment occurred, but it seemed most probable that more thorough training, particularly as it concerned co-operation in the use of Fishpond and H2S, was most desirable.

(1) 'The Operational Performance of Fishpond and Monica III, October 1943 to February 1944,' 16 March 1944. Bomber Command O.R.S. Report No. S.133. (A.H.B./IIH/241/22/14).

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Copies of the report were circulated to Groups by the Radar section with an accompanying injunction to intensify training, and early in May the Training branch set up a permanent committee at H.Q.B.C., on which O.R.S. was represented, in order to progress training in Radar devices. There was, however, always a shortage of equipment for training with tail-warning devices, and it was always difficult to improvise methods of training in devices, the real difficulties of which were closely associated with operational conditions. The only method of demonstrating the need for training appeared to be the collection of separate statistics for trained and untrained operators. Squadrons were asked to mark the untrained operators on the pro forma rendered for each operation. It was soon evident that the Squadron standard of training assumed for this purpose was very variable, and a Command standard of four operational sorties with the equipment was laid down. Statistics collected on this basis failed, however, to show consistent results.

Photography of the Fishpond Display Operations

The casualty statistics during the summer of 1944 revealed little benefit attaching to the use of Fishpond, and analysis of the performance of the device in combats produced a picture of failures to warn similar to that shown in Report No. S.133 mentioned above. Information from operators indicated that the main causes of failure were the number of friendly contacts received which precluded avoiding action being taken on every contact, the high minimum range which in operational experience often proved to be considerably higher than the 400 yards thought to be excessive in the preliminary trials, and poor co-operation between the H2S operator and the wireless operator using Fishpond. T.R.E. were attempting development of means to reduce the minimum range and to make control of the Fishpond presentation more independent of H2S settings, but it appeared possible that some improvement in the interpretation of the signals received might be achieved if the appearance of the signals could be studied at leisure. O.R.S. therefore proposed in August 1944 that photographs of the Fishpond P.P.I. should be taken on operations. The Radar section, then obtaining useful results with the photography of H2S pictures, were agreeable but in the face of shortage of suitable cameras were reluctant to deflect any photographic effort from H2S. The proposal therefore languished until in November, after much pressure from O.R.S.,

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trials were initiated at B.D.U. It was not until mid-March 1945, however, that it became possible to take photographs on operations. After some preliminary trials it was found that 10 second exposures produced films which, when projected, gave a good representation of what had been displayed on the Fishpond tube.[1]

By projecting the pictures in succession on to tracing paper, it was possible to plot the track of selected contacts relative to that of the bomber. There thus appeared to be good prospects of being able to estimate how many of the contacts should be regarded as behaving in the manner expected of fighters, and ultimately of perceiving whether there was any hope of establishing a crude identification system on the characteristics of approach. It was, of course, also possible to count the total number of contacts obtained, a value useful in estimating the bombers concentration as well as in gauging the Fishpond operator's embarrassment, and to study the effects produced by the high minimum range.

The war in Europe came to an end before substantial progress could be made towards positive results. It was, however, established that the use of photography when possible should form an essential part of operational research into tail-warning devices with a visual presentation.

A.G.L.(T)

Initial Development of A.G.L.(T)

The use of radar-aided gun-laying for bomber turrets became an apparently realisable project towards the end of 1942. In a paper communicated to the Technical Aids to Night Bomber Defence of the Operational Research Committee (TANBC/7 of 24 November 1942), D.D.S.R. Arm. outlined the two schemes which had been prepared by T.R.E. and R.A.E. O.R.S. discussed these schemes within H.Q.B.C. and the trend of opinion was that development should be carried to a stage at which the radar device and turret would automatically search the hemisphere to the rear of the bomber. The most advanced of the schemes submitted had automatic search only within a 30° cone and made it necessary that the gunner should maintain a constant controlled movement of his guns in order that the desired field to the rear of the aircraft should be searched. The Command felt that this was undesirable, and as a result of discussions with T.R.E. it appeared that there was a possibility of increasing the effective radar beamwidth for searching to 60°, and of reducing thereby the strain on the gunner.

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(1) O.R.S. Report No. 140 - 'Photography of the Fishpond Tube on Operations as a Research Method'. (A.H.B./II/39/1).

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When the schemes already advertised to the Command were submitted by Air Ministry for a definite decision, O.R.S. recommended that a scheme involving some manually aided searching should not be discarded until the possibility of using the 60° beamwidth had been explored in a trial flight. This suggestion was initially accepted but after further discussion a Command decision was taken to ask for development of a model having fully automatic searching as the first objective, although this involved the setting back of the production of any form of radar aid to gunners by some months.

However, when in June 1943 Fishpond was developed as the first tail-warning device bearing a visual presentation of the direction of contacts, Air Ministry suggested that with the aid of this device to give prior warning of the direction of approach of other aircraft, the need for complete rearward cover of the gun-laying aid would be unnecessary. As a result of trials watched by the Radar section, the Command agreed that a combination of the first available gun-laying scheme with Fishpond would meet its requirements.

Concentration of effort was accordingly switched back by T.R.E. to the development of a device known as A.G.L.(T) Mark I. Trials were carried out at B.D.U. and preparations were made for a crash production programme. The form of A.G.L.(T) developed was a complete centimetric radar installation attached to the rear turret. The effective beamwidth of the radiation was 30° but the aerial system system was arranged to rotate with the guns in elevation and with the turret in azimuth, so that by manipulation of his turret and guns the gunner could keep the rear hemisphere under radar observation. The presentation was combined with the Mark IIC Gyro Gunsight. The gyro graticule was superimposed on the radar picture, both being projected to infinity in the direction of the target aircraft. The radar picture indicated the position of the target aircraft by means of a spot which grew wings when a contact was obtained. Radar range was fed to the gyro sight. It was thus possible to open fire with accuracy on an approaching aircraft on radar information alone, and since the range of pickup was 4,000 feet firing could be carried out before visual perception of the target.

It was the possibility of a bomber opening fire on a fighter before being sighted that made A.G.L.(T) most attractive. Other tail-warning devices made possible on receipt of a warning only evasive manoeuvre, the value of which was always in some doubt against attack by a fighter equipped with a good A.I. There

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was, however, a very serious difficulty in that no distinction between friend and foe could be made by A.G.L.(T), and although with other tail-warning devices the mistaken assumption that a radar contact was due to a fighter could only mean waste of avoiding action, with A.G.L.(T) it might involve the shooting down of a friendly aircraft.

Development of Identification Systems for use with A.G.L.(T)

When the schemes for A.G.L.(T) were first propounded, it was assumed that an aircraft carrying the device would, on receipt of a radar contact, be able to manoeuvre and would regard as hostile any aircraft which followed it. By the end of June 1943, however, experience with Monica had shown that such a means of identification was impracticable with the concentrations of aircraft then being used on operations. This point was made by O.R.S. to the Air Staff, and it was urged that A.G.L.(T) would be a much less effective warning device and useless for blind firing if provision were not made for means of identifying contacts. The Radar section agreed wholeheartedly and urgent steps were taken to explore all possibilities.

During the next few months a great many discussions were held at T.R.E., R.A.E B.D.U. and the Admiralty Research Laboratory (A.R.L.), concerning possible methods of identification. In these O.R.S. was much concerned with the particular functio of expounding the relative numbers of friendly and hostile contacts likely to be received on an operational sortie, and the high degree of reliability which an identification system must have in order to permit firing blind.

One scheme emerged which offered a possibility of being brought to operational readiness at a reasonably early date. This was to equip all bombers with an infra-red transmitter in the nose, and to provide A.G.L.(T) equipped aircraft with a suitable receiver. Trials carried out at B.D.U. in December 1943 demonstrated the practicability of this scheme, and it was decided to develop it for operational use. The receivers used were known as Type Z and this name became attached to the system as a whole.

It was evident that the Type Z system had potential drawbacks. In the first place it was clearly open to the enemy to instal infra-red transmitters in the noses of his fighters. Although the possibility of overcoming this counter by flashing the infra-red signal in a code was open, it was considered that the enemy

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might be able to pick up the code at an early stage of the operation with receivers placed on the ground, and to transmit details to the fighters. It was also suggested that the infra-red transmissions from the bombers might be received on the ground and used for plotting the course of the bombers, or received in the air and used for homing. These problems were much discussed.

The principal measure considered was to screen the transmitters so that their radiation should be cut off over an angle below the aircraft. Although the angle of cut off required to prevent observation from the ground could readily be estimated, the effects on the use as an identification device were complicated. The questions involved were considered theoretically by O.R.S.(1) It was pointed out that the cutting off of the angle from which the infra-red lamps could be seen must involve a ban on blind firing for those directions in which an identifying signal could not be received, and that the prescription of those directions would take into account the effect of aircraft banking. It appeared that with the cut off at 30° below the horizontal apparently necessary to prevent cut-off on the ground, the limitations on the angle for blind-firing would have a serious effect on the expected value of A.G.L.(T).

The Command view, developed in discussions between the Air Staff, Armaments branch and O.R.S., became firmly that the introduction of any cut-off involved such restrictions that it should be avoided if possible, and that therefore although preparations should be made for a cut-off when necessary A.G.L.(T) should begin operations with the fullest possible angle of identification. It was hoped that should the enemy begin to read the code of the Z transmitters, knowledge would soon be obtained from his radio transmissions to his fighters. There was in any case a reasonable expectation that a period of at least a month would elapse before the enemy could make serious use of the infra-red transmission. Preparations went ahead on this basis, although not without many discussions as disturbing scraps of information about the enemy's development of infra-red receivers were obtained, and as technical difficulties in the preparation for a possible later introduction of the cut-off arose.

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(1) O.R.S. Memo M.70 - 'Effect of Aircraft banking on Infra-Red Identifications'. (A.H.B. Un-indexed).

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There seemed nothing to fear from enemy exploitation of the Type Z system for a period at least, and the greatest anxiety to O.R.S. was that the system would not prove sufficiently serviceable to avoid more losses to our own aircraft as a result of firing by A.G.L.(T) on misidentification than were saved by the use of A.G.L.(T) directly. This question was considered quantitatively.(1)

It was assumed that the use of blind-firing would not save more than 2 per cent of sorties, and the reliability of the identification system required to ensure that less than 2 per cent of sorties was shot down by A.G.L.(T) fire was estimated on the basis of the number of contacts estimated as coming into range during an operation, and of the assumption that half the bombers fired at would be shot down. The result obtained was that a reliability of 99•6 per cent was essential. Assuming that the unserviceability was equally divided between transmitter and receiver, a reliability of 99•8 per cent in the receivers appeared essential. It was shown that if 10 per cent of the receivers were to fail during the course of a flight, the required degree of reliability should be obtained if gunners tested their receivers every 10 minutes.

The degree of realiability required was so high that it seemed that in spite of the small size of the equipment, enemy action damage might be an important factor in reducing reliability. This hazard was therefore estimated for the Z transmitters from their size and position and from statistics of enemy action damage. It was estimated that the transmitter would be damaged once in 9,000 sorties by flak, and once in 5,000 sorties by fighter attack, giving a consolidated estimate of enemy action damage once in 3,000 sorties.(2)

Preparations for Introduction into Operations

During the summer of 1944, the difficulty of keeping bomber losses to a low level during the coming winter was generally thought to be considerable. The enemy had so organised his fighter defences that he appeared likely to take heavy toll of concentrated bomber raids, and apart from a complete change in bomber tactics which was being actively studied, A.G.L.(T) was the only equipment which seemed likely to give an important new aid to bomber protection. Therefore, it was the view of many including O.R.S. that every effort should be made to gain experience with A.G.L.(T).

(1) O.R.S. Memo M.69 - 'Efficiency Required of the Type Z Identification Equipment'. (A.H.B. Un-indexed).

(2) O.R.S. Memo M.72 - 'Preliminary Estimate of the Vulnerability of the Infra-Red Type Z Apparatus in Heavy Bombers'. (A.H.B. Un-indexed).

In a discussion O.R.S./T.R.E. on 21 June 1944 it was agreed that A.G.L.(T) ought to share with the Wurzburg jammer Carpet II the claim to highest priority among the radar devices for bomber defence.(1) Consequently, although there were shortcomings to the equipment, especially in regard to the identification system, the O.R.S. view was that, while making reasonable preparations to meet enemy reactions and to improve performance, an operational trial should be carried out as soon as possible. The fact that the identification system might have a limited life caused some concern as to whether it would not be better to delay introduction until a large number of aircraft could be fitted, as had been argued for Monica. However, A.G.L.(T) required that its operators should be well-trained and the assistance in training which could be expected from a body of operationally experienced instructors, and the urge to find out all faults before the large-scale introduction, outweighed this consideration. Further complications were introduced by the necessity that infra-red identification should not be compromised by use over enemy territory before certain military use of the idea had been made.

By the beginning of July 1944 it was possible to operate a few aircraft of one squadron with A.G.L.(T), and although at that time the whole Command was not fitted with Type Z transmitters the Air Staff decided that A.G.L.(T) should be operated with the limitations that it should only be used for blind firing when carried in a force wholly fitted with Type Z. The tactical instruction issued by the Air Staff to cover initial operations with A.G.L.(T) was based on the results of trials conducted by B.D.U. Gunners were instructed to manipulate their turret and guns to make a regular radar search through angles of $\pm 60^\circ$ in azimuth, 60° down and 30° up in elevation every 30-40 seconds. Fishpond or Monica was to be used as an accessory search device. Fire was to be opened at all approaching aircraft which did not show on Type Z identification at a range of 700 yards, and was to be kept up to 400 yards. Then, if the approach continued, avoiding action was to be taken. Great emphasis was, however, laid on the need for care to avoid shooting at friendly aircraft.

(1) T.R.E. Memo to D.C.D. reference 4/16/2 of 23 June 1944.

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Early Operational Experience

The first squadron to be equipped with A.G.L.(T) was No. 460, and eight aircraft of this squadron used the apparatus on operations for the first time on the night of 18/19 July 1944. An O.R.S. representative was stationed with the squadron for this, and a number of subsequent operations, in order to interrogate the crews and to devise a suitable form for the recording of all the information which they were able to obtain. The early operations promised well. The difficulties foreseen were not as great as had been feared, and none turned up unforeseen. A pro forma was devised for the regular supply of information on operational sorties to H.Q. Bomber Command. This pro forma was considerably more detailed than those employed for other tail-warning devices, a feature made desirable by the greater implication of the device, and made possible by the fact that the gunners using it were specially trained and, as pioneers, a specially keen body. Later, when a good deal of detailed information had been obtained, and A.G.L.(T) was being fitted on an expanded scale, ~~an expanded scale of A.G.L.(T) fitting~~ a simpler form was prepared in conjunction with the Radar section.

A second squadron, No. 49, brought A.G.L.(T) into operational use in September 1944, and was visited by an O.R.S. representative during the introductory period. Again promising results were obtained, and at the end of October, when the total of A.G.L.(T) sorties for the two squadrons was 536, only 6 aircraft (1·1 per cent) had been lost compared with an 'expected' number of 11 calculated on the hypothesis that the device had no effect.

There were, however, some disturbing features made obvious in O.R.S. personal investigations at the squadrons and in the specially written returns made in the O.R.S. pro forma - the serviceability of the A.G.L.(T) and of the Type Z receivers were both disappointingly low and there were no successes claimed for blind-firing. It is appropriate to refer here to a difficulty which occurred for other devices but which was especially striking for A.G.L.(T). Squadrons were always being urged to keep serviceability high by the appropriate technical branch at Command, and sending in returns which indicated that it was not as successful as other squadrons incurred signs of displeasure from headquarters. Although this probably had the effect of reducing real unserviceability, it certainly had a real marked effect on reducing the unserviceability recorded on papers. Defects and

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errors of adjustment sufficient to make the apparatus unusable on an operation but requiring little effort to rectify, were not recorded by the technical officers. They were, however, recorded on the operational returns by the aircrews. Thus, for the period July-September, the unserviceability rate recorded by the technical officers was 9·2 per cent, whereas the O.R.S. operational returns indicated that on 45 per cent of the sorties A.G.L.(T) had been unusable for at least part of the operation. Unfortunately, the O.R.S. records of unserviceability were not accepted by the technical branch which preferred to rely on its own statistics and at a time when great efforts should have been made to improve A.G.L.(T), T.R.E. were congratulating themselves on having produced an equipment remarkably free from troubles. In consideration of the Type Z system the O.R.S. opinion carried greater weight since no technical branch had any experience of this form of equipment. It was therefore possible to stimulate some activity in attempts to improve the serviceability. Those attempts initiated by O.R.S. Memo M.71 'A.G.L.(T) in No. 49 Squadron, with Special Reference to Type Z Telescopic Serviceability', (1) were actively helped by O.R.S. visits to R.A.E. and A.R.L., and to the squadrons to secure and try out suitable test gear for the Type Z receivers.

Possibilities of Exploitation of A.G.L.(T) Radiation by the Enemy

The introduction of A.G.L.(T) came at a time when knowledge of the enemy's use of bombers' radiations for plotting and homing had caused some disquiet about all forms of radiation. As far as A.G.L.(T) was concerned, the danger of its use for plotting had not been considered so long as other radiations were also being emitted, and it was hoped that any fighters homing on to it would be shot down by its aid. However, by the end of September 1944, the failure of A.G.L.(T) to achieve successes by blind-firing and provisions being made for the restriction of H2S radiation, suggested that further consideration should be given to these matters.

A preliminary statement for the advice of the C.-in-C. was prepared as a matter of urgency by the Signals branch and O.R.S. in collaboration. This, based on judgment of the basic principles, suggested that so long as the number of A.G.L.(T) aircraft operating was less than 40, little aid would be given to the

(1) A.H.B. Un-indexed.

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enemy's plotting as he would be unable to appreciate the difference between A.G.L.(T) and A.I. Mark X used by groups of fighters on bomber support operations, but that larger numbers must involve either restrictions on radiation or the operation of A.G.L.(T) aircraft as a separate force. It was considered that provided A.G.L.(T) equipment remained serviceable it should be capable of dealing with homing fighters but, in view of the proviso, the serviceability would need to be improved to 80 per cent before A.G.L.(T) aircraft operated as a separate force.

The questions involved were then probed more deeply by O.R.S. and a full report was issued.(1) The probable enemy schemes for use of A.G.L.(T) radiation were first considered in the light of existing knowledge of his equipment and of the radiation characteristics. It was considered that although the A.G.L.(T) radiation was beamed and directed astern, the swinging of the turret and 'spill' outside the main beam would enable the enemy's ground organisation to D/F on A.G.L.(T) much as he could on H2S. Preparations to arrange for the restriction of A.G.L.(T) radiation outside enemy defended territory were therefore urged. Similar considerations applied to enemy homing with airborne receivers on to a bomber stream containing a proportion of A.G.L.(T) aircraft. It would not constitute an additional hazard so long as H2S was used over enemy territory but should the use of that device be deemed dispensable then the A.G.L.(T) aircraft should operate as a special force.

Homing of enemy fighters on to individual A.G.L.(T) aircraft did not appear to be an easy achievement. So long as the gunner was rotating his turret, the signals produced by his A.G.L.(T) in an enemy homing receiver would fade periodically. However, as soon as the gunner picked up a fighter, searching would cease and the fighter would know that he had an A.G.L.(T) aircraft at fairly short range. It was estimated that in a concentrated bomber force wholly equipped with A.G.L.(T), a fighter flying along the stream might hope to obtain a useful contact of this sort about once every five minutes.

The homing risk appeared to be sufficiently grave to warrant a rather more careful examination of the ability of A.G.L.(T) to shoot down an enemy fighter than had been made previously. The vulnerable areas of various types of enemy fighters

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(1) 'The Possible Exploitation of A.G.L.(T) Transmission for Plotting and Homing, 10 October 1944.' Bomber Command O.R.S. Report No. B.226. (A.H.B./IIH/241/22/12).

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to the several forms of ·303 and 0·5 inch calibre ammunition available were estimated from the results of firing trials issued by M.A.P., with correction for known changes in enemy armour (A.G.L.(T) then in use was fitted to turrets firing 4 x ·303 guns, but there was a prospect of conversion to 0·5 guns later). The results obtained in B.D.U. trials with gunners under training were then used to estimate the number of bullet strikes which could be expected on the vulnerable area of an approaching enemy fighter. It appeared that, if the instruction to fire continuously as the range closed from 700 to 400 yards was carried out, an average of about four strikes on vulnerable areas should be obtained using the ·303 ammunition mixture then being used by the A.G.L.(T) squadrons. It was concluded that A.G.L.(T) aircraft had a reasonable chance of shooting down an enemy fighter, and should be able to accept a risk of homing. The low serviceability of A.G.L.(T) was, however, mentioned.

The possible substitution of 0·5 inch calibre ammunition for ·303 inch did not promise a great increase in the chances of destroying enemy aircraft as the increase in area of the enemy fighter vulnerable to the larger was only doubtful compensation for the reduced rate of fire. It did appear, however, that a change of the composition of the ammunition belts to give a high proportion of incendiary bullets might be worthwhile for all bombers. The conclusions referring to A.G.L.(T) were accepted in the Command and preparations to enable A.G.L.(T) to remain switched off until enemy territory was reached were put in hand.

Further Operational Experience

The collection of statistics and the analysis of gunners' reports was continued. There were complications in that on some operations the use of the equipment for blind-firing was not permitted, and on others incompletely trained gunners were unable to make full use of the device. Personal contact with the two using squadrons made possible the keeping of records for each gunner and an accurate picture on the performance of A.G.L.(T) in full use was obtained.

When more than 1,000 sorties had been flown with A.G.L.(T) by trained crews, the record was considered in detail.(1) It was shown that the low loss-rate of A.G.L.(T) aircraft as compared with the other aircraft of their Group which had

(1) 'Initial Operational Experience with A.G.L.(T)', February 1945. Bomber Command O.R.S. Report No. S.205. (A.H.B./IIH/241/22/14).

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been striking during the first three months of operation, had not been maintained during the later period. It was considered that this effect might result from the decline in fighter opposition which had been in progress since the previous September. The numbers were in any case too small to reveal anything but a large effect. However, when consideration was given to the performance of A.G.L.(T) in combat, it was clear that the full benefit expected from the use of the device was not being obtained. There had been at least 16 occasions on which A.G.L.(T) contact and Type Z identification should, on the basis of the operational instructions, have involved blind-firing. On only four of these had fire in fact been opened before a visual was obtained. Neither on these four occasions nor on six others when A.G.L.(T) was used for firing after visual identification had a claim for the destruction of a fighter been allowed.

The technical performance of A.G.L.(T) when serviceable had been reasonably satisfactory as a warning device. In 34 approaches of enemy aircraft from astern or quarters, only one attack had taken an aircraft using a serviceable A.G.L.(T) by surprise. On 10 occasions, however, the equipment was unserviceable and a high rate of unserviceability was confirmed by the overall operational record.

The deficiencies of A.G.L.(T) were thus fairly well established as poor serviceability as had been previously pointed out by O.R.S., and a reluctance of the gunners to open fire blind. The reason for the gunners' reluctance could be deduced from their reports and was confirmed by personal contact with some of them. They had little confidence in the Type Z system. Instances had occurred of aircraft, subsequently identified visually as friendly, approaching without showing a Type Z signal. On other occasions hostile aircraft had approached too rapidly to permit Type Z identification in the time interval between pick-up on A.G.L.(T) and the point at which avoiding action became desirable. Further, serviceability of the receivers was poor.

Investigation of the records of individual gunners showed that the human element was likely to play a large part in such a device as A.G.L.(T), and suggestions were made for improved selection and training procedure.

Chapter 19

Study of Aircraft Vulnerability

Before the war, and indeed for the first two years of the war, there was little concrete evidence as to the mechanism by which aircraft were destroyed by enemy defences. There was a general belief that the main causes were loss of petrol from a holed tank, stoppage of an engine, killing of the pilot, or damage to the controls etc, and various measures were taken in the early war years to combat these risks.

During the summer of 1941 it was decided by the Ministry of Aircraft Production (A.D. Arm. R) that it was essential to obtain some precise information relating to cause of losses and the damage sustained by those aircraft which succeeded in returning; accordingly, in September 1941 an officer was posted to the Bomber Command Operational Research Section which was then in process of formation, with the specific task of making the investigation.

Preliminary Study of the Problem

A careful study was made of all the existing returns to the Command Headquarters which might assist in the analysis. These consisted of:-

(a) E-Forms.

(b) Z-Forms.

(c) Casualty Signals.

(d) Circumstantial Reports on Casualties to Personnel.

(e) Flight Engineers' Logs in the Case of Heavy Bombers.

The E and Z Forms proved to be of negligible value for this purpose since it was, in general, impossible to deduce the precise aircraft to which any report of damage related and in addition the information was meagre and often inaccurate as the reports were compiled from the statements made by crews at interrogation before it had been possible to make an accurate daylight inspection of the aircraft. Casualty signals were of slightly more value but they had many defects from the point of view of the analysis in hand. In the first place a casualty signal was only raised if a member of the crew was injured, or if the damage to the aircraft was beyond the capacity of the unit to repair. In such cases the damage was assessed as being in one of the following categories:-

/ Cat. AC

Cat. AC - Repairable on site by R.A.F. or contractors working party.

Cat. B - Repairable at contractors works.

Cat. E - Complete write-off.

Secondly, the brief details of the damage included in the casualty signal were directed rather towards assisting the Salvage Organisation to decide on the tools required than towards giving details for analytical investigation.

The circumstantial reports were of little value as they tended to be written from a humanitarian point of view and often dealt rather with the circumstances of the flight as a whole than with the precise details of injuries etc. They tended to be journalistic rather than scientific.

At the time this survey of available data was carried out there were very few heavy bombers in service and hence few flight engineers' logs were produced. In addition the logs were then in a very elementary stage and were largely concerned with fuel consumption.

A series of visits to stations was made to examine aircraft which had been damaged and a comparison was made between the actual damage and the details as obtainable from the existing reports. From this survey of data (and from discussions with the Command technical staff) it became obvious that some more detailed and precise form of reporting would be required if useful conclusions on the vulnerability of aircraft were to be reached, and a tentative pro forma to be completed for all damaged aircraft was produced.

It was felt that if a special damage report was introduced, the description of the location of the damage would be greatly facilitated by the inclusion of outline diagrams on which the damage could be marked. Preliminary discussions were held with the Deputy Directorate of Scientific Research III of the Ministry of Aircraft Production (D.D.S.R.III of the M.A.P.) who arranged for the R.T.P. Drawing Office to prepare drawings as specified by Bomber Command O.R.S.

Concurrently with these preliminary investigations an approach was made to the M.A.P. liaison officer of the Directorate of Repair and Maintenance (D.R.M.) to obtain details of the repair procedure for aircraft damaged beyond unit capacity for repair, and to ascertain what information they had available. The procedure adopted by this organisation on receipt of a casualty signal was for No. 43 Group to send a crash inspector to confirm the category of the damage and to obtain details of any damage caused to civilian property by a crashed aircraft.

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If the aircraft was Cat. B or E it was dismantled to its transport sections and removed under No. 43 Group arrangements to the works of a civilian contractor (this was often, but not necessarily the firm which originally produced the aircraft). On arrival at the works the aircraft was inspected by the Aeronautical Inspection Department (A.I.D.) (or the works inspector under the supervision of the A.I.D.) and an 'Inspection Report' was produced detailing all repairs to be carried out and all modifications to be incorporated. The salvage procedure which at that time dealt almost exclusively with medium bombers (in the case of Bomber Command) was such that the whole aircraft with the exception of the engines was delivered to one contractor.

As a result of this approach a visit was made to the Headquarters of No.43 Group and after a useful discussion with a representative of D.R.M. it was decided that it would be desirable to make a visit to the works of contractors carrying out such work. Visits were accordingly made to Messrs. Vickers at Weybridge, and Messrs. Brooklands Aviation Ltd., both of which were engaged on the repair of Wellington aircraft, and were selected on the advice of No. 43 Group, who effected the necessary introductions. The detailed inspection reports produced were examined, and after discussions with the Inspectors-in-charge of the A.I.D. it was felt that although the detailed inspection reports might be too cumbersome since they contained much detail irrelevant from the O.R.S. point of view, a useful report could be produced by the A.I.D. inspectors with the aid of the works inspection staff.

The Collection of Data

Having established that the production of a useful damage report on all Cat. B aircraft was feasible, a visit was made to the Headquarters of the Aeronautical Inspection Department where the Assistant Director of Inspection (Airframes) A.D.I.(A) proved most helpful. He agreed, with the approval of the Director-General of the A.I.D., that provided it did not take up too much of the inspector's time, that the A.I.D. would complete for all Cat. AC (fly-in) and Cat. B aircraft, a report on the lines of the pro forma which had previously been drawn up. The reports when complete were to be sent direct to O.R.S. and not via the A.I.D. and it was decided that the scheme should start as soon as the necessary pro forma and diagrams could be produced. There was some delay in the

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production of drawings but a supply became available towards the end of February 1942, and instructions were sent out by A.D.I.(A) on 24 February initiating the scheme of reporting by A.I.D. inspectors.

In parallel with the negotiations with A.I.D., further steps had been taken to inaugurate a Damage Reporting Scheme within the Command, and on 28 December 1941 a meeting was held at the Headquarters to discuss the matter. The group engineer and armament officers, together with representative engineer and armament officers from one station in each group, attended the meeting which was presided over by C. Eng. O. The pro forma, previously mentioned, was agreed after slight amendment to be suitable for completion on stations for each aircraft damaged by enemy action, and it was also agreed that appendices to the pro forma giving details of the type of information required should be prepared and sent to all stations.

There was considerable discussion as to the procedure to be adopted in the completion of the forms, but it was finally agreed that they should be completed in the first place as far as possible by the Intelligence Officer on information gained at interrogation from the crew that their aircraft had been damaged by enemy action. The form was then to be sent to the Station Engineer Officer who would add engineering details and arrange for the other specialist officers to add their information. The form when completed was to be sent within seven days direct to Headquarters Bomber Command (H.Q.B.C.). In the case of aircraft landing away from base at other Bomber Command stations, the report was the responsibility of the station at which the aircraft landed and was to be forwarded to the parent station for onward transmission to H.Q.B.C.

As a result of the meeting a letter was sent to all groups issuing copies of the revised pro forma together with instructions for its completion and photographs showing damage typical of various types of German ammunition. It was to take effect from 5 January 1942.

During the first month of operation of the report some squadrons co-operated well and supplied excellent reports, but others either sent in no reports at all or sent in ones of such inferior quality that they were of negligible value. A month after the introduction of the report it was considered necessary to send a further letter to all groups requesting that the quality of information might

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be improved and reminding them that reports were to be rendered for all aircraft which sustained enemy action damage. The preliminary issue of drawings arrived towards the end of January and opportunity was taken to send out supplies of them with the above-mentioned letter. It was suggested that if two or three aircraft were damaged at the same time the damage could all be marked on one drawing using a different colour for each aircraft. This letter had the effect of raising the quality of the reports received, but had a much less marked effect on the number of cases of damage reported.

During the first few months of operation of the report, many queries relating to vulnerability were received and dealt with, but it was felt that there was not yet sufficient data to merit the writing of a full report on the vulnerability of any particular component.

Initially the damage reporting scheme was only applicable to Bomber Command, but towards the end of March 1942 there were discussions at the Operational Research Committee on the desirability of extending it to all Home Commands, and Bomber Command was asked to supply details of the scheme then in operation. A meeting of representatives of all home O.R.S.s and the Directorate of Operational Requirements (D.O.R.) was held at Air Ministry on 29 March 1942 at which the report forms and the procedure in use in Bomber Command were discussed. The report form, while perfectly satisfactory for bomber aircraft was unsuitable for use with single engined fighters and coastal aircraft, and Bomber Command O.R.S. was requested to draw up a form which would be suitable for universal application throughout all Home Commands.

A further meeting was held at Air Ministry on 23 April 1942 when the revised pro forma was discussed, and after some modification had been made it was agreed to proceed with the scheme. A representative of the Air Ministry Technical Intelligence Branch, A.I.2(g), attended the meeting and stated that they were willing for their inspectors of crashed enemy aircraft who were in general stationed at maintenance units in various parts of the country, to give any assistance they could in the inspection of our own damaged aircraft. The offer was gladly accepted and it was arranged that A.I.2(g) would assist by examining as many aircraft as possible of Bomber and Coastal Commands which had sustained severe damage as a result of fighter attack. This scheme came into operation at once; the A.I.2(g) officers received notice of all severe damage from the FB Crash signals

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which were repeated to the nearest maintenance unit (M.U.). In addition they were advised by O.R.S. of the aircraft which were most likely to yield useful information, on occasions when several were damaged during the same period.

The recommendations of the meeting of 23 April were implemented by letter from Air Ministry dated 5 June 1942, addressed to all Home Commands requesting that they would take part in the Damage Reporting scheme and that they would provide mutual assistance when aircraft landed away from Base at an airfield belonging to a different Command. Damage to aircraft of Fighter Command was, at the request of that Command, for the time being excluded.

The first 'Thousand Plan' raids of 30/31 May and 1/2 June 1942 brought new complications as the original instructions for reporting enemy action damage did not include Nos. 91 and 92 Groups which operated for the first time on these occasions. It was considered highly desirable to learn as much as possible about the effects of these large numbers of aircraft on the enemy's defences, and accordingly a special return giving details of the number of flak strikes and the place, time, and height of the aircraft when damaged was called for from these two groups, as it was considered impracticable to arrange for complete damage reports of the type required from normal operational squadrons to be rendered.

During the first few months of operation of the damage report, a careful watch was kept on the number of damaged aircraft for which a report was received as assessed from the E-Forms (later Raid Reports) etc, and it was found that some squadrons hardly reported any damage while others reported a fair amount with the result that the reports received formed a sample of unknown quality and magnitude of the total damage sustained. In view of the type of information requested from O.R.S. by A.A. Command, M.A.P., and the Air Ministry, it became obvious that if the information was to be of real value something must be done to provide a datum level on which to assess the reports received, and it was decided that the most satisfactory method would be to establish some members of the O.R.S. staff at two or three of the Bomber Groups. It was intended that these damage inspectors would ensure that all damage was reported on the squadrons with which they were based and would, in addition, assist as far as possible with the reporting of other damage in the group.

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This proposal was considered by the Command to be a good one and approval was given to put the scheme into effect by a meeting of the Operational Research Committee on 25 June 1942.

An additional measure to improve the standard of the reporting of technical details of the damage was explored during the summer of 1942 and this led to certain changes in the procedure for reporting damage.

It was thought that the failure to submit reports containing sufficient detail of the damage sustained might possibly be due to the fact that engineer officers, who were required to complete the section 'Description of Damage' in the report might be unaware of the existence of the notes, which had been circulated with the letter initiating the damage form, to assist in the examination of the aircraft and the compilation of the report. This seemed particularly likely as the letter was circulated under an Air Staff reference and it was proposed that a leaflet should be published for inclusion in the Bomber Command Engineer Staff Instructions giving all relevant details.

Considerable discussion on the responsibility for rendering damage reports took place and it was ultimately decided that the Int/Ops Staff should initiate and co-ordinate the information obtained from the specialist officers. The instructions were promulgated on 20 September 1942, and on 5 October a suitable leaflet for incorporation in Bomber Command Engineer Staff Instructions was issued.

During the late autumn of 1942 it was decided to prepare an enlarged and revised set of photographs of typical damage and finally a complete report entitled 'Notes to Assist in the Examination of British Aircraft Damaged by Enemy Action' was produced by the Orfordness Research Station and copies were distributed throughout the Command during January 1943. Copies were also prepared for use by the other Commands participating in the scheme.

Meanwhile the recruitment of damage inspectors had proceeded; the first two arrived in the autumn of 1942 and the remaining two followed at the end of the year. Each inspector (who was by training a civil engineer) spent a few weeks at Bomber Command Headquarters to become familiar with the work of the Section, and then attended short courses at the Royal Aircraft Establishment (R.A.E.) and Orfordness to become familiar with the layout of the aircraft in use in the Command and also

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to obtain first-hand information of the type of damage which enemy fighter ammunition was capable of inflicting on an aircraft. Motor cycles were obtained so that the inspectors might be fully mobile, but owing to the fact that only one of the inspectors was a competent motor cyclist it was necessary for the others to attend a course of instruction at the R.A.F. M.T. School at Weeton.

The first inspector to be placed in the field was the one appointed to No. 5 Group and he took up his duties in the middle of February 1943. Arrangements were made to accommodate this inspector at R.A.F. Station, Waddington, where he was supplied with living and office accommodation. At the commencement of his duties, the head of O.R.S.2(c) accompanied the damage inspector round the group and met the station commanders and engineer officers and this initial tour was found very useful. A letter was sent by the group engineer officer to all stations in the group outlining the revision of the procedure of damage reporting, consequent on the appointment of a damage inspector. The main change was that damage reports when complete were to be sent to the group's damage inspector and not to H.Q.B.C. It was pointed out that the appointment of this inspector did not absolve the stations from making a report in the usual way, but that the damage inspector would assist the engineer officer in its compilation, particularly in the case of aircraft which had sustained extensive damage.

The next inspector to go out into the field was attached to No. 3 Group and was stationed at the Group Headquarters, taking up his duties on 1 May 1943. A preliminary discussion was held with the S.A.S.O. of the Group, but the head of the Section did not accompany the damage inspector on his initial tour. However, this offer did not materialise and the difficulties of the inspector in initiating the scheme were thereby increased.

It was felt desirable that before they went out by themselves, the two remaining inspectors should obtain some experience of the work they would ultimately be called upon to undertake, as by this time the damage inspector at No. 5 Group had become well established and accordingly they were attached to Waddington for a short period. It was decided that only one of these inspectors should be posted to a group (No. 4 Group), and that the other should remain based at ~~this~~ Bomber Command Headquarters to enable him to examine aircraft which landed in this vicinity and south of the Thames. This policy was found to be amply justified

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in view of the fact that considerable numbers of aircraft landed at airfields along the south coast, e.g. Ford, Tangmere etc, and later at the emergency airfield at Manston. It was also found convenient to use this inspector to assist the other inspectors at times of exceptional operational activity or to relieve them for periods of leave.

The damage inspector at No. 4 Group took up his duties in August 1943 and was stationed at R.A.F. Base, Pocklington. Prior to his arrival for duty the A.O.C. sent a letter to all stations in the group informing them of the terms of reference of the damage inspector and requesting all station commanders to meet him on his initial visit and thereafter to give him all facilities to carry out his work.

The introduction of damage inspectors was very successful in improving both the quality and quantity of damage reports, and gave those responsible for the analysis of the data confidence in their material. The service engineer officers were too busy to ensure that the data provided by their staff was sufficiently accurate, and the presence of an officer who could give full-time to this work was invaluable. As time went on it was found that owing to climatic conditions, motor cycles were an unsatisfactory form of transport and these were replaced by light cars. These gave the added advantage that the inspectors could carry round a drawing board and could more easily write up their notes on the site. This was a great help, particularly in inclement weather.

The reporting of damage in No. 6 (R.C.A.F.) Group was found to be particularly bad and in June 1944 a service engineer officer supplied by R.C.A.F. Headquarters was posted to the group. He did much to improve the standard of reporting, but just as he was becoming really useful with the experience gained he was posted away and another officer took his place. This process was repeated several times with the result that the value of the damage inspector in that group was only a small part of what it might have been, and reporting efficiency of the group remained low right to the end of the war.

Soon after the damage inspector at No. 5 Group took up his duties he learned that the contractors working parties engaged on the repair of Cat. AC aircraft prepared lists for each aircraft showing details of the repairs considered necessary, and the part numbers of all components which had to be replaced. These reports were considered to be very useful to the O.R.S. as they covered aircraft

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which had fairly severe damage and also gave details of internal damage which only came to light when the machine was opened up for repair. Arrangements were accordingly made for the supply of a copy of all such reports on Cat. AC aircraft prepared by Messrs. A.V. Roe and Co, and it was possible to obtain copies of the reports which had been prepared in the past. These reports proved to be of such great value to us that arrangements were made to obtain similar reports from Messrs. Handley Page Ltd, Messrs. Sebro Ltd, and R.A.F. maintenance units. It was found, however, that the reports prepared by Messrs. A.V. Roe and Co., were much more informative than those obtained from other sources.

Recording of Data Received

Initially, the damage reports on receipt in O.R.S. were given a serial number and particulars of them as follows were entered in an index (this book came to be known as the 'Black Book' from the fact that the original volume had black covers):-

(a) Report Number.
(b) Date of Sortie.
(c) Squadron and Aircraft Letter.
(d) Aircraft Type, Mark and Number.
(e) Cause of Damage.
(f) Category of Damage.

The index at this time was compiled as the damage reports were received, and accordingly the entries were not classified into any particular group. As advances were made in the collection of data corresponding advances in the recording of the data were introduced.

Raid reports for individual aircraft superseded the E-Forms in May 1942, and they gave a much better check on which aircraft were damaged, together with supplying more details of the effect on the aircraft of the damage than were usually given on the damage forms. Frequent reference had to be made to the raid reports and with effect from 1 December 1942 it was decided to extract and summarise all damage details given on raid reports as soon as they were received. This information was entered on loose-leaf sheets in a folder (which for convenience was called the 'Red Book'), and the following details were recorded:-

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(a) Date.
(b) Target.
(c) Group.
(d) Type of Aircraft.
(e) Squadron.
(f) Aircraft Letter.
(g) Aircraft Number.
(h) Name of Captain.
(i) Bombload.
(j) Time of Take-off.
(k) Time of Landing.
(l) Place of Landing.
(m) Place, Time, Height and Speed when Attacked.
(n) Bombing Height and Time.
(o) Description of Damage.
(p) Cause of Damage.

In addition, details of the category of the damage and reference to other reports such as casualty signals, damage forms etc, were included. It was necessary from time to time to make slight additions and alterations to the layout of the sheets in order to meet changing circumstances and requirements. (The 'Red Book' was found to be so useful that it was subsequently completed retrospectively to the beginning of 1942).

With the introduction of the 'Red Book' further attempts were made to ensure that details of all damage were obtained, and telephone calls were made to defaulting units for outstanding damage forms. This had the desired effect, but the expenditure of time made it desirable to introduce some simpler method of ensuring the rendition of damage forms. A printed form, on which could be entered details of the raid report and aircraft concerned, requesting the submission of a damage form was therefore prepared and these were sent off about four or five days after a raid. In groups where a damage inspector was stationed these requests were unnecessary and details of all damaged aircraft within those Groups were passed to the damage inspectors at the earliest opportunity for necessary action.

Several other modifications in the recording procedure were also introduced with effect from 1 December 1942. The first of a series of fortnightly summaries giving details of all aircraft damage, raid by raid, after 1 December was published at the end of December. This summary in the first instance included

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only aircraft damaged by enemy action, but later all damage sustained in the air was included. In December 1943 the summary was further improved and gave details of all enemy action damage and other damage sustained in the air, together with all crashes and other incidents, resulting in damage whether due to enemy action or not, provided that it was incurred in operational flying. The final version of the summary was a complete record of all operational wastage in Bomber Command after the inclusion of missing aircraft with effect from November 1944. Details of the number of strikes by various missiles on aircraft damaged by enemy action were also given. This summary became the final authority on the numbers of aircraft damaged by enemy action and was accepted as a basis for the Air Ministry War Room figures. It also superseded a much less accurate monthly report, published by the War Office (M.I.15) giving the numbers of aircraft damaged by flak.

With effect from 1 June 1943 the 'Black Book' became a much more orderly document. Damage forms were put into folders on receipt and were not immediately given a number and entered into the index. There was one folder for each operation and within each folder the damage reports were filed in numerical order of groups, and within each group in numerical order of squadrons, and finally in alphabetical order of aircraft letters within the squadrons. Two or three weeks after the date of an operation, when it was thought that most damage reports had been received, they were numbered and entered into the index in the order above mentioned. Spaces were left in the index for outstanding reports which it was thought would arrive later. Another column was also added to the index giving the author or authors of the reports. For instance, there might be a Cat. AC report in addition to a report by the squadron. There was no duplication in effort, in having reports from two such sources as the squadron report detailed strikes of missiles and with the aid of the Cat. AC report it was possible to assess the internal damage attributable to any given strike.

In addition to damage forms, O.R.S. received copies of all FB casualty signals. Those for aircraft missing or damaged by enemy action were retained by the O.R.S. but those for aircraft damaged by other causes were only supplied on loan in view of the limited number of copies available, with the result that they had to be copied out in order that our records might be complete. The casualty signals were divided into:-

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(a) Aircraft Missing.
(b) Aircraft Damaged by Enemy Action.
(c) Aircraft Damaged not by Enemy Action.

and were bound into three volumes each month in chronological order and squadron order within dates. It is believed that these records are unique.

There was an instruction that all flight engineers' logs were to be forwarded to this Headquarters and large numbers were received and filed. There was an unfortunate tendency, however, for squadrons to fail to submit logs for aircraft which had been in any way damaged or in which a technical failure had occurred. Logs were received by O.R.S. for the majority of sorties between January 1943 and the end of the war.

Selection of Problems for Analysis

In deciding the priority in which analyses of the vulnerability of various components or systems should be carried out, two basic principles were followed;
(a) an analysis was undertaken at the specific request of an interested party, or
(b) an analysis was made of the system when it was felt that there was sufficient data on damage to that system to make the results of such an analysis significant.

Method of Analysis of Data

The method of analysis of the data naturally varied with the problem concerned, and changes were made to suit the work to the ability and number of analysts available. Initially the information was analysed with the assistance of a ledger system which was divided into several classes, e.g. casualties to crew, damage to engines, fuel systems, oil systems, turrets, dinghy etc. There was one page in the ledger for each major item of the aircraft and each page was divided into the following columns:-

Report No. Type of Aircraft. Cause of Damage. Description of Damage.

When it was desired to make a study of a particular component, the relevant pages of the ledger were consulted and a table of the following form was constructed:-

/ Type

Type of Aircraft	Cause of Damage	No. of Reports Received	No. of Cases of Damage to component in question
Blenheim	Heavy Flak Light Flak Fighter		
Hampden	Heavy Flak Light Flak Fighter		
Total	Heavy Flak Light Flak Fighter		

In addition a series of appendices was published (one for each type of aircraft) setting out by causes the details of the damage given in the ledger. The body of the report contained a discussion of the implications of the number of cases of damage and its severity along with recommendations for improvement to the component concerned. It should be noted that the early analyses included only information obtained from damage forms although it was known that these were not a complete record of all the damage that was sustained. It was, however, the best that could be done at the time.

The whole of the work of maintaining the ledger and the compilation of such reports was at that time carried out by the scientific personnel. The ledger system was reasonably satisfactory when the number of damage reports was small, but when they began coming in in large numbers it became unwieldly and had to be abandoned due to lack of staff to cope with it. Instead it was decided to introduce a Paramount (1) system card index and this was started in December 1942. A card was produced for every aircraft damaged and all known information relating to the damage to a particular aircraft was entered on the card. On the first

(1) The Paramount system consists of a series of uniformly spaced holes around the outside of a card. Each card, of which there is one per aircraft damaged, has holes in identical positions. Each hole represents a variable of the data to be recorded, e.g. there is a hole for damage by flak, another for damage by fighter etc. For any given variable which applies to a given aircraft, a clip is made in the card extending the hole to the edge of the card so that there is a 'V-shaped' indentation in the card (e.g. for an aircraft damaged by flak a clip is made in the 'Flak' hole). The cards are sorted by means of needles inserted through the holes and shaking out the clipped cards.

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type of card used, a considerable amount of space was devoted to the recording of the sources from which the information came and the identity of the aircraft.

It was, of course, wasteful of time and card to make out one of the large cards for aircraft which sustained only minor skin damage due to flak, and accordingly a further set of much smaller Paramount cards was used for the recording of such damage.

When it became necessary to obtain further stocks of cards owing to the consumption of the original set it was decided to modify the layout of the cards in the light of experience gained with the first set. On the new cards many more holes were devoted to the recording of technical details of damage than had been the case on the earlier cards. The cards were compiled by the scientific personnel and carried manuscript details of the identity of the aircraft together with full information as to the number of missile strikes with the damage caused. In this form they were found very useful for obtaining fairly quick answers to specific questions, but again owing to shortage of sufficient skilled personnel it was not possible to keep them anything like up-to-date and they eventually lagged behind the receipt of reports by seven or eight months.

It was felt that the card system would have been quite satisfactory if it could have been kept up-to-date, but the time spent in making the cards was rather great, and unless a considerable number of fairly skilled personnel (about the standard of Assistant III) were available to keep them up-to-date, a better result would probably have been achieved by conducting two or three running analyses by means of a ledger system.

When it became impossible for the scientific personnel to cope with the production of the large number of cards required an attempt was made to dilute the labour by the use of laboratory assistants and a simplified procedure was instituted. The laboratory assistants were required to write on the cards the identity of the aircraft and the date of action together with the category of damage and details of the sources of information. They were to clip the cards in the appropriate holes but were NOT to write out details of the damage as it was found to be beyond the abilities of the laboratory assistants available to describe accurately the technical details of the damage sustained by the various components. Eventually the production of the cards was discontinued altogether as it was found

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that the accuracy of the assistants in this respect (and it must be remembered that the work required considerable judgement and technical ability) was not very good and the checking of the cards absorbed a great deal of the scientific personnel's time.

The method of analysis of a problem for a period covered by the completed cards was relatively simple. The cards relating to damage to the component under examination were selected by the sorting needle and these were then further sorted into date order, type of aircraft, and cause of damage. Tables of the type outlined above were then drawn up permitting a quantitative study of the damage details to be made. Technical details of damage were entered on to a suitable pro forma allowing a qualitative study of the damage to be made. It should be noted that by the time the cards were first produced O.R.S. had some information of practically every aircraft damaged (irrespective of whether or not a damage report was returned) and that the cards contained details of damage extracted from all the sources of information available and not solely from damage forms, so that in compiling the appendices of the report it was sufficient to copy the details from the cards without reference to any other source of data. The tables in the report now related the frequency of damage to sorties of aircraft and a total number of aircraft damaged by the various causes instead of to the number of damage reports received.

The analysis of a problem for a period covered by the partially completed cards (Laboratory Assistant work) was more lengthy. The procedure was to select the relative cards by means of the sorting needle and thus to obtain the identity of the aircraft concerned, together with details of the sources of information relating to the damage. It was then necessary to consult these reports individually to draw up the pro formae after which the analysis proceeded as before.

After the discontinuation of the cards it became necessary to modify the method of extraction of the basic data for a report. The analyst now had to consult all the reports in order to determine which ones contained an account of damage to the component under examination, instead of only those indicated by the cards, in order that the tables and pro formae might be completed. The task of reading through the reports, some of which were very bulky, was very laborious and a check revealed that when the work was done by the scientific staff, they overlooked about 1 per cent - 2 per cent of the cases reported.

A further attempt was made to use the laboratory assistants on this work, but a check on their accuracy showed that they omitted some 20 per cent of the reported cases and occasionally included spurious cases. The cases they overlooked appeared to be a random selection and in order to improve this low figure of accuracy, arrangements were made for two assistants independently to carry out the extraction of data for a given period and then for the results to be compared. The first assistant completed the full details on the pro forma, but the second one merely produced a nominal roll of the cases concerned. Details of missing cases so discovered were looked up and added to the pro forma during the checking stage. It was found that the accuracy of the final result was comparable to that achieved by the scientific staff, although it was often necessary for the scientist conducting the analysis of the pro formae prepared by laboratory assistants to consult the original data in order to add missing details. This scheme led to a useful saving in scientific manpower.

During the course of the various analyses a useful technique was developed to determine the expected number of flak strikes on any particular component. A report was produced giving details of the total number of flak strikes on the heavy bombers, dividing the data into raids on German targets, targets in occupied territory etc. Distinction was also made between strikes from above and below and a value was obtained for the number of strikes per aircraft damaged. When it was desired to calculate the expected number of strikes on any given component, its plan area was calculated and expressed as a fraction of the total plan area of the aircraft. This fraction was multiplied by the number of aircraft damaged and the strikes per aircraft damaged, thus giving an upper limit for the number of strikes to be expected on the component during the period under consideration. Allowance was then made for the thickness and toughness of structure and equipment lying vertically above and below the component and a better estimate of the expected number of strikes was obtained. This method could not be used to give an absolute measure of the lethality of strikes on the particular component but was useful in the comparison of different aircraft.

Another technique which was found useful was to plot the position of all recorded strikes on the plan and under plan diagrams of the aircraft. For this purpose diagrams to the scale of ¼ inch to 1 foot were found most suitable. When

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a large number of strikes had been plotted the density of strikes on the various parts of the aircraft was examined. Uniform density indicated the absence of particularly vulnerable parts. Low density in any given area was indicative of either:-

(a) high vulnerability of a component in that area
or
(b) screening of the area by another component.

An examination of the aircraft revealed which of these two items was the correct explanation. This technique was found valuable in studies of strikes by falling incendiary bombs on aircraft flying at a lower altitude.

Results of Investigations

At this stage it would perhaps be well to point out that before the introduction of this scheme there was no data whatever available to the Air Ministry and munufacturing firms relating to the damage sustained by aircraft on operations, and hence the selection of various types of power unit and other components was from a vulnerability point of view based on impressions and theoretical considerations. It is most regrettable that as far as is known no records were maintained of the cause of loss of aircraft during the 1914-1918 war, or of the damage they sustained during the first two years of the Second World War. If this had been done it would have been possible to make use of facts which have now come to light, but which were learned too late to be of much value in this war owing to the long delay between the first indication that modification was required and its final appearance in operational aircraft. These delays, which were apparently unavoidable in the circumstances, in some cases (particularly in the case of fire-prevention modifications, about which more is said below) resulted in Bomber Command sustaining higher losses than it would otherwise have done.

There now exists a great volume of data relating to some 17,000 damaged aircraft of Bomber Command which, when fully analysed, will undoubtedly provide most useful conclusions for the framing of operational requirements for future aircraft which, judged by present standards, are reasonably orthodox. It is felt that the information gained will be of value in the design of jet aircraft in relation to future types of missile.

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During the first months of operation of the scheme it was of course impossible to draw many useful conclusions from the data as they did not cover a sufficiently large number of cases to be statistically significant. However, some attempt was made to supply guidance on vulnerability problems, in response to requests, in January 1942. The first problem to be raised was the comparative vulnerability of air and liquid-cooled engines, but all that could be done in those days was to supply details of the missing rates of the various aircraft then in operation. There were definite indications of the greater vulnerability of liquid-cooled engines.

The next problem to be raised concerned the comparative vulnerability of hydraulic and electro-hydraulic turrets. The data available were very scanty but the vulnerability of hydraulic systems appeared much higher than the electro-hydraulic system of the Halifax aircraft.

In May 1942 a conference was held at the Army Operations Research Group to discuss the Fragmentation of A.A. shells and Damage to aircraft. O.R.S. produced a report entitled 'Preliminary Note on Statistics Relating to the Effectiveness of Enemy A.A. Shells'[(1)] for discussion at the conference. It contained information from the first 200 damage forms received, and indicated that the great majority of aircraft damaged by heavy flak received only two or three strikes. There were few cases of aircraft having more than 20 strikes. The report also showed that strikes from below were twice as numerous as those from above - a result which was of value in assessing the type of engagement by which flak damage was caused, and one which also assisted in calculation of the expected number of strikes on components in various parts of an airframe.

At the end of May an enquiry was received as to whether the casualties of mid-upper gunners in fighter attacks was unduly high. It was possible to state that they were no higher than for other positions in the aircraft and that additional armour plate was not necessary.

During the whole of 1942 there was frequent correspondence with A.A. Command, A.ORG., and the Ordnance Board, relating to the best size of flak fragments to inflict the maximum damage and also relating to the numbers of strikes etc by light flak and the effects produced.

(1) O.R.S. Report No. 39.

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The first full-length report published and dealing with technical details of damage inflicted on our aircraft, was compiled from information contained in the first 400 damage forms received. It was entitled 'A Note on the Vulnerability of Various Aircraft Fuel and Oil Systems to Enemy Action' and was prepared in September 1942.(1) Details of the frequency of damage to various components of the system were provided and attention was called to the vulnerable position of the fuel cock control cables and of the outboard engine oil tanks on the Halifax. It was also pointed out that the risk of fire in the wings proving lethal was greater than had been supposed in the past.

In February 1943 an enquiry was received from Air Ministry (O.R.6) regarding the frequency with which the ammunition tracks to the rear turret were jammed as a result of enemy action, as the policy for turrets was being hardened for some new types of aircraft, and it was not desired to perpetuate ammunition tracks if these were specially vulnerable. It was possible to reply that it was a rare occurrence for tracks to jam and it was pointed out that a far more serious contribution to the vulnerability of the aircraft was made by the hydraulic system of the turrets. This latter statement brought a further request from D.O.R for more detailed information on the vulnerability of hydraulic turrets, and a short note was prepared giving details from 450 damage reports. It indicated that the rendering of an electro-hydraulic turret unserviceable by enemy action was rare compared with the frequency of the occurrence in a hydraulically operated turret.

The next component to receive attention was the armour plate protection. The Air Ministry wrote a letter in February 1943 stating that an investigation was being made into ways and means of reducing the weight of the equipment in heavy bombers to improve their performance, and suggesting the engine armour as one of the items for removal. It was desired to know whether this armour was effective so that it would not be removed if it had been found of value. A short note was produced setting out all cases of damage reported on the first 700 damage reports, and pointing out that although few instances of strikes on

(1) O.R.S. Report No. 57 (A.H.B./IIK/54/6/5).

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engine armour were known, it was thought probable that such cases might have passed unnoticed by the engineer officer's inspections in view of the inaccessible position of the plate and the difficulty for anyone not an armour expert to distinguish between normal irregularities on a plate and the slight marks made by fragments, the energy of which was insufficient to defeat the plate. In view of the known severe risk of fire when an engine was damaged it was recommended that the engine armour should be retained, but it was suggested that the main fuselage armour bulkhead might be deleted with very much less risk, and that the saving of weight would thus be considerable. Both these recommendations were adopted.

A close watch was kept on all fragments of enemy heavy flak shells found lodged in our damaged aircraft to ascertain whether they presented new or unusual features. Early in March 1943 a remarkably rectangular shaped fragment exhibiting signs of longitudinal cuts on the outside face struck and lodged in an aircraft flying over Essen. This fragment was immediately sent to the Ordnance Board with the suggestion that it might be controlled fragmentation to give large fragments. Several other fragments exhibiting similar characteristics were recovered from the same vicinity within the next few weeks, and forwarded to the Ordnance Board. It was, however, several months before they were convinced that the fragments were really produced by control.

In reply to an enquiry dated 12 July 1943, a letter was sent to Air Ministry giving details of all known strikes on self-sealing oil tanks, together with remarks on the efficiency of the self-sealing covers. It was pointed out that operational experience gave little evidence to contradict the experimental results obtained at R.A.E. which showed that the self-sealing on an oil tank could rarely be expected to be of value. There was considerable discussions with R.A.E. and M.A.P. on this matter, and when later it was felt that the saving in crude rubber, of which the supply was critical, would be substantial, this section recommended the substitution of a crash proof felt covering in place of self-sealing cover. This was agreed and put into service.

There had always been considerable interest in the angle above or below the datum line at which enemy fighters attacked our bombers, and in August 1943 a note was sent to M.A.P. (D.D.S.R. III) showing that by far the greatest number of

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attacks at that time came from dead level or less than 10° below level. It was pointed out that these figures related to returning aircraft and might not be truly representative of those attacked and shot down.

On 28 September 1943 a meeting was held with representatives of the Structural and Mechanical Engineering (S.M.E.) Department at R.A.E. to discuss general vulnerability problems etc, and in passing it was stated that in the opinion of Bomber Command O.R.S. the proportion of losses due to various causes at that time was made up as follows:-

Fighters	-	75 per cent
Flak	-	20 per cent
Other Causes	-	5 per cent

At the end of November 1943 an enquiry was received from C. Eng. O. stating that self-sealing petrol pipes were giving a good deal of trouble (and in fact had been responsible for crashes) by sealing internally and cutting off the flow of fuel, even when the pipe had received no enemy action damage, and requesting information as to how frequently they were hit by enemy missiles. A reply was sent to the effect that during a 4-month period there were 25 recorded cases of damage to pipes and of these the self-sealing was certainly not effective in half the cases. It was suggested that the self-sealing on the main feeds to the engines might safely be deleted. A meeting to discuss the possible deletion of self-sealing hoses was held at M.A.P. on 23 December 1943, and O.R.S. produced figures which showed that self-sealing pipes were barely worth the weight involved, and certainly not worth the risk of failure obtaining at that time, and it was decided to recommend to D.O.R. the deletion of self-sealing pipes. This was later agreed and self-sealing pipes ceased to be fitted on bomber aircraft.

The next problem to present itself related to the vulnerability of oxygen bottles. Firing trials at Orfordness had shown that under certain circumstances oxygen bottles exploded when struck by large calibre bullets and it was desired to ascertain whether such bottles in heavy bombers presented undue hazards. A detailed analysis was carried out and it was concluded that when carried in their stowage positions in heavy bombers the oxygen bottles were not a dangerous store.(1)

(1) 'Assessment of the Vulnerability of Oxygen Bottles to Enemy Action Damage.' Bomber Command O.R.S. Report No. S.118. (A.H.B./IIH/241/22/14).

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During May a request was received for a report on the numbers of flak holes in damaged aircraft covering a more recent period than Report No. 39. Discussions were held with the Ministry of Supply Armament Research Department, and it was agreed that a member of the staff of the Chief Superintendent of Armament Research (C.S.A.R.) should be attached to assist with the analysis as it was felt that although the information would be of great value to gunnery experts it would be of less use to Bomber Command and the Air Ministry. The report eventually prepared was issued and used as a basis for A.A. gunnery performance calculations by C.S.A.R.'s staff.(1)

About the middle of May 1944 M.A.P. (D.D.R.D. Inst.) stated that at that time the adoption of high voltage 3-phase AC supply for large aircraft was proving a very live policy issue between M.A.P. and the Air Staff, and requested that O.R.S. might assist in clearing one issue which affected the details of that policy, namely whether on vulnerability grounds it would be satisfactory to have an earthed neutral or whether it was desirable to employ an all insulated system. A meeting was arranged between representatives of D.D.R.D. Inst. and O.R.S. on 30 May at which it was agreed that in view of the speed with which the information was required and the complexity of the problem, it would be impracticable to carry out a full-scale investigation into the matter. However, there was in course of preparation at that time a report on the comparative vulnerability of the hydraulic, and electro-hydraulic turret systems, and it was decided to publish an interim report entitled 'Preliminary Note on the Vulnerability of the Turret Systems in Halifax Aircraft', giving details of the frequency of damage to electric cables. This report was published in June 1944 and indicated that an earthed negative system should be perfectly satisfactory.(2) It also indicated that the hydraulic turret system in the Lancaster is effectively about five times as vulnerable as the electro-hydraulic system in the Halifax. It showed, in addition, that the number of cases of damage to the electrical part of the turret system among returned aircraft was surprisingly small, being only one case in 450 sorties. This report brought a sharp retort from the exponents of hydraulic turrets, but it was possible to show that all the objections they raised to the report were without foundation.

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(1) 'Statistics of Damage to Aircraft due to Heavy Anti-Aircraft Fire.' Bomber Command O.R.S. Report No. S.165. (A.H.B./IIH/241/22/14).

(2) 'Preliminary Note on the Vulnerability of the Turret Systems in Halifax aircraft.' Bomber Command O.R.S. Report No. S.163. (A.H.B./IIH/241/22/14).

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In July 1944 a report entitled 'Preliminary Note on the Vulnerability of Aero Engines' was published.(1) This report showed that liquid cooled engines were more than twice as vulnerable to enemy action than air-cooled engines. The large number of failures were mainly due to damage to the coolant system and in particular to the radiators. Over half the cases of engines failing due to coolant system damage were hit in the radiator. As a result of this report discussions were held with the Engineer Branch and Messrs. Rolls-Royce. It was pointed out by O.R.S. that the weight of armour to protect the radiators proposed by Messrs. Rolls-Royce was intolerable and that the low level coolant warning device and low pressure oil warning device previously asked for were a very pressing requirement.

The next major report to be issued dealt with the 'Vulnerability of Hydraulic and Electrical General Services in Heavy Bomber aircraft'.(2) This report again drew attention to the very much greater vulnerability of a hydraulic system than that possessed by an electrical system. It was pointed out that up to 95 per cent of hydraulic services hit were rendered unserviceable, whereas the proportion of electrical circuits which were unserviceable following damage was certainly less than 62 per cent and very probably less than 45 per cent. The report was supplied to the Society of British Aircraft Constructors as a guide to principles to be followed in future designs.

As a result of the above report and of Report No. S.163, together with discussion held with D.D.R.D. Inst., C.R.D. was enabled to decide on a high voltage 3-phase A.C. supply system, with an earthed neutral, for large aircraft of the future.

Late in 1944 a report entitled 'The Vulnerability of Flying Control Systems in Heavy Bomber Aircraft' was prepared with the assistance of a member of the Structural and Mechanical Engineering Department of R.A.E.(3) This report indicated that probably about 5 per cent of missing heavy bombers were lost due in some measure to damage to flying controls. Loss of elevator control was shown to be lethal in most cases, and it was recommended that whenever possible that

(1) O.R.S. Report S.160. (A.H.B./II H/241/22/14)
(2) O.R.S. Report No. S.196. (A.H.B./II H/241/22/14).
(3) O.R.S. Report No. S.215. (A.H.B./II H/241/22/14).

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elevator control should be duplicated over its whole length. The use of the Saunders system of controls, in the Halifax, was shown to lead to a reduction in the number of aircraft having severed trimming controls, but to increase the chance of loss of an aircraft of which the main controls had been severed. It was pointed out that a considerable improvement might be effected by operating the elevator trimming tabs from the rudder push-pull tube and the rudder trimming tabs from the elevator push-pull tube. It was suggested that in a control system employing separate main and trimming controls the rudder and elevator main control tubes should be placed on opposite sides of the fuselage and that the trimming controls should be on the side remote from its corresponding main control.

The intruder activity on the night of 3/4 March 1945 resulted in 22 of our aircraft being destroyed over the United Kingdom, and a further eight damaged. A careful and detailed study was made of the damaged aircraft and of the wreckage of those destroyed. The combat reports and eye-witness accounts were also considered. The findings showed, as had long been held by Bomber Command O.R.S., that fire was the major agent of destruction of our aircraft shot down by enemy fighters (in fact about 90 per cent of the aircraft destroyed that night were on fire in the air).(1) It also confirmed our belief that there is no significant difference, apart from fire, between the damage inflicted on aircraft which are shot down and those which survive the damage, and that the majority of fighter attacks on our aircraft came as a complete surprise to the crew.

The last report published on vulnerability during the war was entitled 'Final Report on the Vulnerability of the Turret Systems in Heavy Bomber Aircraft'.(2) The great vulnerability of the hydraulic system was again emphasised, and in addition it was pointed out that a hydraulic system is much more liable to fire than an electrical system. The layout of the systems in the Halifax and Stirling was shown to be reasonably satisfactory from a vulnerability point of view, but the fact that the hydraulic pipes run through the bomb-bay in the Lancaster renders them unduly vulnerable to enemy attack.

The Fire Risk

Undoubtedly the greatest single hazard associated with aircraft is that of fire in the air, and O.R.S. did a considerable amount of work both to bring this to the notice of M.A.P. and Air Ministry and to assist in experiments designed to ascertain the causes of such fires and to develop remedial measures.

(1) O.R.S. Report No. S.217. (A.H.B./IIH/241/22/14).
(2) O.R.S. Report No. S.222. (A.H.B./IIH/241/22/14).

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It was in May 1942 that this section first took an active interest in the problems associated with the fire risk in the air, following a suggestion by R.A.E. that there was a greatly increased risk of explosions in fuel tanks if one of them was drained during flight. This led to considerable discussions as to the feasibility of leaving some petrol in each of the tanks, and also regarding the conditions of temperature and pressure obtaining on operational flights, so that a better estimate could be made of the expected frequency of there being an explosive mixture even in partially filled tanks. It was considered impracticable to leave petrol in a tank, apart from the small amount normally remaining after running an engine on the tank until the engine misfired, and it was agreed that nothing useful was likely to be achieved by trying to vary the procedure for the use of petrol or the design of tanks. A series of flight engineers' logs and other data relating to the maximum rates of dive achieved on operational flights was supplied to M.A.P. to assist in the calculations of the mixture strength likely to be found above petrol level in a tank at various stages of the flight by a bomber. R.A.E. carried out extensive trials and calculations on the atmostphere likely to be found above fuel level in aircraft tanks, and in August 1942 published a report, No. Ch 333, entitled 'Report on the Probable Frequency and Danger of Explosive Mixtures in Fuel Tanks during Operational Flying'.

In September 1942 a letter was sent to R.A.E. stating that some 25 per cent of the enemy aircraft destroyed over this country fell in flames, and suggesting that at least a similar proportion of our aircraft were lost in the same way. About this time an analysis was made of the reports by returning aircrew of the number of aircraft seen falling in flames, and it was found that even making allowance for the known use by the enemy of pyrotechnic devices to simulate this phenomenon the risk of fire appeared unexpectedly high. A suggestion to account for this high fire risk was the possible presence of explosive vapour in the inter-tank spaces in the mainplanes, and it was decided to investigate the possibility of this being caused by the careless refuelling of tanks.

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Careful measurements of the vapour concentrations both during and after refuelling were made on Wellington, Halifax, Lancaster and Stirling aircraft and the results were published in a report entitled 'A note on the possibility of the presence of explosive mixtures in the mainplanes of aircraft'.[1] It was found that ground crews often allowed considerable quantities of petrol to overflow from the top of a tank during refuelling, but that all aircraft, with the possible exception of the Stirling, had sufficiently 'leaky' mainplanes to allow any excess petrol spilt in refuelling to flow away before any dangerous concentration of petrol vapour could be built up, so that the risk from this cause was negligible.

At about this time R.A.E. published a further report (No. Eng.52) dealing with the prevention of explosions in fuel tanks and outlining a scheme for the provision of an inert atmosphere in tanks by supplying nitrogen from high pressure bottles. The possibility of obtaining the inert atmosphere by making use of the engine exhaust gas was also mentioned, although this had not reached such an advanced stage of development as had the high pressure nitrogen system.

A general interest in accidental fires in aircraft was stimulated by a meeting held at R.A.E. on 6 November 1942, and convened at the request of C.I.(Accidents), who pointed out the high loss of aircraft and personnel from this cause. It was agreed at the meeting that the drill to be followed in the case of an engine fire should be changed to the following:-

(a) Warn the crew.
(b) Close throttle.
(c) Feather propeller.
(d) Turn off petrol.
(e) Switch off ignition.
(f) Press graviner extinguisher button when the engine has come to rest.

(The previous drill had been to turn off the petrol and open the throttle, and was designed to combat the now comparatively rare carburrettor intake fires). It was also agreed to be desirable to disconnect the automatic flame switches from the graviner system and to arrange for them to operate fire warning lights in the cockpit. Several fire prevention modifications were suggested, but it was emphasised that one of the greatest factors for overcoming engine fires was the fully feathering propeller.

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(1) O.R.S. Report No. 56. (A.H.B./IIH/258/1/184).

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The meeting of 6 November 1942 was followed on 9 November 1942 by another meeting called by D.D.S.R. III to discuss the causes of fire in aircraft due to enemy action. At this meeting Bomber Command O.R.S. gave a review of the importance of the problem, and stated that a certain amount of information was obtained from crews who had seen other bombers shot down over enemy territory. From this an attempt had been made to determine what proportion of missing aircraft fell in flames due to flak and fighter. During the period mid-August to the end of October 1942 it seemed likely that about 40 per cent of aircraft missing were shot down in flames.

There was considerable discussion regarding the sources of fires and the O.R.S. ~~section~~ gave the following figures for the numbers of aircraft which had returned after having had fires in the air during the period May to August 1942. These were as follows:-

Engine Fires	Not due to enemy Action	38
	Due to Flak	10
	Due to Fighter	8
	Due to either Flak or Fighter	1
	Total	57
Tank Fires	Due to Fighter	4
	Not due to Enemy Action	2
	Total	6
Other Items	In Fuselage or Skin - Flak	4
	In Fuselage or Skin - Fighter	4
	Electrical faults - Not Enemy Action	5
	Electrical faults - Enemy Action	1
	Incendiary load - Fighter	3
	Incendiary load - Not known	1
	Total	18
	Grand Total	81

Methods of prevention of fires and explosions in tanks were the first items to be discussed. The question of the ability of inert A.A. fragments to produce tank fires was raised, and D.S.R. called attention to some recent trials in which some 1¼oz fragments fired with a velocity of 3500 ft/sec. against self-sealing tanks with dural deflector plates had caused fires in two cases out of eight shots. Various reasons were put forward to explain the mechanism of such fires, and D.S.R. pointed out that he considered it important to examine precisely what happened when fragments were fired at dural. The Rond Research Laboratory (D.S.I.R.) were carrying out a series of experiments to discover the effect of firing fragments through inflammable mixtures, and it was expected that this would determine whether ordinary flak fragments had sufficient velocity to cause ignition.

R.D. Arm.3 mentioned the risks associated with the incendiary load and referred specifically to the fact that photo-flash flares invariably exploded somewhat violently when hit by a missile. It was pointed out by the O.R.S. that about six months prior to the meeting only a proportion of Bomber Command aircraft carried flash flares and a comparison had been made of the loss rates of aircraft with and without flashes. The results showed that those carrying flash flares suffered only very slightly greater losses. However, armoured flare chutes went a long way to reduce the risk and they were a definite requirement by Bomber Command.

On 23 November 1942 a discussion was held at R.A.E. and O.R.S. again pointed out that it considered that some 40 per cent of our aircraft which were missing were shot down in flames, and suggested very tentatively that from the small amount of information available the location of the fires might be apportioned as follows:-

50% in the engines.
35% in or around fuel tanks.
15% in other parts of the aircraft.

There was no direct evidence as to whether fires started on the inside or on the outside of tanks and the potential dangers of these two localities were discussed. It was thought, however, that the most likely origin of tank fires was the ignition of an explosive fuel vapour - air mixture inside the tank by a single shot, and it was considered that measures to prevent explosions in tanks should be given priority over those designed to deal with fires starting externally.

After the meeting there was a demonstration of the explosion of tanks at low temperatures when attacked by incendiary ammunition. Two self-sealing fibre (replica German) tanks of 40 gallon capacity and containing 10 gallons of petrol (RDE/F/100) were cooled to $-20^{\circ}C$ and one round of 0·303" B Mark IV incendiary ammunition was fired at each through the space above the petrol. Both tanks exploded and burst into flames.

In view of this convincing evidence that one strike by an incendiary bullet on a tank at a low temperature could result in such a serious fire, and of the fact that the fire and explosion risk contributed a considerable amount to our bomber losses, a letter dated 26 November 1942 was sent to M.A.P. by O.R.S.

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suggesting further trials at high priority. ~~It was pointed out that we~~ O.R.S. considered that it would be of the utmost value to repeat this trial using a flak fragment against a British tank, since if an explosion could occur in these circumstances it would be of primary importance to press on with the scheme for introducing an inert gas in fuel tanks. It was essential to use a British tank since these have unpainted aluminium baffles, on which an inert fragment is likely to cause a spark, whereas the tank used in the above-mentioned trial had fibre baffle, unlikely to cause a spark when struck by an inert fragment. It was pointed out that owing to the large estimated weight of the nitrogen system for a Lancaster, the Command would probably be reluctant to accept it unless it had convincing proof of the very real danger of such explosions.

There was considerable correspondence between M.A.P. (D.D.S.R. III) and ~~this Section~~ O.R.S. as a result of the above-mentioned letter. During the course of this it was stated by M.A.P. that as far as could be ascertained from an analysis of Fighter Command Combat Films, few real explosions seemed to occur and that it seemed likely that if the mixture strength in a tank was not uniform there would be a local explosion which would not completely burst asunder the tank. It was accordingly suggested that damage inspectors should be instructed to examine damaged tanks for bulges. In response to these suggestions Bomber Command O.R.S. agreed that explosions of a rather minor character occurred under certain conditions, but pointed out that these explosions seemed to disrupt the tank, leaving the surrounding wing structure undamaged. The petrol appeared, however, to be ignited and the fire caused lethal damage to the structure.

There was another meeting at M.A.P. on 20 November 1942, when action was taken to implement the recommendation made at the meeting of 6 November referred to above. Instructions were issued for the modified fire drill to come into effect at once, and for the disconnection of the flame switches from the Graviner fire extinguisher system. During the course of the meeting C.Eng.O. (B.C.) mentioned the proposed torque reaction warning light at the feathering button to indicate engine failure and advocated the connection of the flame switch to the feathering mechanism of the propeller so that the propeller would automatically be feathered in the event of engine fire. R.A.E. favoured the idea that the flame switches should operate a warning light only, owing to the risk of accidental

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feathering of the propeller. It was suggested that the torque reaction warning light might be made to flash in the event of fire or to give a steady light in the event of power failure, to avoid additional warning lights.

At the end of December 1942 O.R.S. published a report entitled 'A Note on the Fire Risk in Bomber Aircraft',(1) calling attention to the high fire risk existing, and giving details of all fires reported among returning aircraft during the period May-August 1942. In addition details were given as far as were known of the number of fires in missing aircraft, together with an analysis of observations by returning aircraft seen falling in flames. The report gave an appreciation of the causes of fires and indicated that 'aircraft are brought down as a result of being hit by a small number of shell fragments in spite of adequate safety factors in structure strength, multiplicity of engines and tanks. The only possible explanation is that fire can be initiated by shell fragments and that fire is the major agent of destruction'. It was recommended that urgent consideration be given to the installation of the nitrogen system for production of an inert atmosphere in tanks, and it was suggested that in the Lancaster the increase in weight involved might be offset by the deletion of the self-sealing covers from the two outboard tanks.

The report was forwarded to the Air Ministry by the D/C.-in-C. on 12 January 1943, requesting that experiments should be carried out in the highest priority to determine the desirability of the introduction of the nitrogen scheme and of more efficient fire extinguishers in engines and the installation of extinguishers around tanks.

In January 1943 R.A.E. carried out further firing trials of incendiary ammunition against various petrol tanks containing explosive mixtures, and obtained explosions with the first shot on each occasion and a start was made to carry out extinguisher trials on fires in running engines.

During the spring of 1943 O.R.S. arranged for B.D.U. to carry out experiments to determine the temperatures experienced inside fuel tanks during the flight, and also itself made measurement of the temperatures inside the fuel tanks on aircraft on return from operations. It was found that the temperatures of the No. 3 tanks in a Lancaster, when empty, followed fairly closely the temperature of the outside air, but the other tanks were kept at a slightly higher temperature by the heat from the engines. In particular, it appeared that the

(1) O.R.S. Report No. S.74. (A.H.B./IIH/241/22/14).

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temperature inside a fuel tank was much higher if the aircraft was flying in sunlight than if it was flying by night. The results of these measurements were forwarded to R.A.E. by whom the information was requested.

The experiments suggested in January were carried out at R.A.E. on 9 April 1943, at a full-scaled demonstration attended by representatives of D.O.R. and of this Headquarters. The details of the experiment were arranged with the assistance of this Section, which made the suggestion that for ease of firing a Robinot (all steel) bullet should be used to simulate a flak fragment. The opportunity was also taken at this occasion to demonstrate the effectiveness of the Methyl Bromide extinguisher installed around a fuel tank in a tank bay.

A short report summarising the results of the trial was prepared by this Section in collaboration with C.Eng.O., and was published on 11 April 1943. The trial had shown that when a Blenheim tank containing an explosive mixture was attacked by a Robinot bullet or by an incendiary bullet, it was burst asunder with such violence that it would have destroyed an aircraft had it been installed in the wing. It was concluded that 'if the petrol and tank are between the temperatures of -10°C and -40°C at ground level or between -25°C and -55°C at 20,000 ft, (conditions which are often obtained in operations) and a tank or tanks are struck above petrol level with an incendiary bullet, in every case a disastrous explosion and/or fire will occur with certain destruction of the aircraft, leaving the crew no possible chance of escape. If struck with an inert bullet or fragment of flak, an explosion and/or fire of the same magnitude as that caused by incendiaries will occur in approximately 50 per cent of the strikes. The frequency of explosions and fire with inert fragments depends on the velocity of the fragment and the amount of structure both external to the tank and internal struck by the fragment. When an inert gas such as nitrogen is introduced into the tank above petrol level, the explosion risk is completely eliminated'. It was therefore recommended that immediate action be taken on the highest priority to incorporate a system for the introduction on an inert gas (nitrogen) above petrol level sufficient for a seven hour flight in all tanks of bomber aircraft, even though this involved an additional weight of 230-250 lb per four-engined aircraft. The report also pointed out that there was little doubt that a system (for the extinction of fires in tank bays) such as that demonstrated would be successful in extinguishing the majority of tank fires, and it was recommended that its development should proceed on the highest priority.

A letter embodying these points was sent to Air Ministry (D.O.R.) on 19 April by the D/C.-in-C. with the approval of the C.-in-C. and agreement was obtained for the introduction of the nitrogen scheme on the highest priority.

A suggestion was made in May 1943 by Air Staff that as an interim measure to reduce the explosion risk of petrol tanks, those tanks which would not be required for use on the short sorties necessitated by the short hours of darkness in summer should be drained and thoroughly purged of vapour by an air blast. This led to much discussion in the Headquarters, and it was decided by O.R.S. to test the feasibility of removing all traces of petrol vapour from a tank under the conditions obtaining on an operational airfield. A visit was accordingly made to R.A.F. Station, Lindholme, where a series of experiments was carried out and from these it was concluded that:-

(a) The length of time required thoroughly to blow out a tank depends largely on the precise attitude of the aircraft on the ground, the efficiency of the scavenging of liquid petrol from the tank, and the care with which the air stream is passed through the tank.

(b) If the tank is only partly freed from petrol vapour, it may permanently be in a more dangerous condition than if it contained about two gallons of petrol.

(c) In view of the necessity of ensuring that all petrol is removed from the tank no matter how much is trapped or imperfectly scavenged, it is thought that it would not be safe to fix the minimum period for which a stream of air must be passed through the tank at less than 2½ to 3 hours.

(d) It would appear to be impracticable for a large number of tanks to be blown out under the normal conditions obtaining on an operational squadron.

It was decided, as a result of this report, to drop the proposal of emptying tanks during the summer months.

During this time the development of improved engine fire extinguishers had proceeded at R.A.E. and Bomber Command was invited to send representatives to witness a demonstration at R.A.E. on 18 June 1943. The demonstration and discussion which followed it were attended by representatives of the Air Staff, Engineer Staff and O.R. Section, and a report entitled 'Fire Risk in Aero Engines and Methods of Extinguishing them' was prepared by the O.R.S. in collaboration with C.Eng.O. This report gave details of the tests seen, and made recommendations for the steps which ought to be taken to reduce the risks from engine fires.

The substance of the report was embodied in a letter sent by the D/C.-in-C. to Air Ministry on 28 June 1943, which called attention to O.R.S. Report No. S.74. It also pointed out that the fire extinguishing arrangements in engines were

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inadequate, and out-of-date, and it was considered that, provided an increase in weight in the extinguisher system could be tolerated, there was a good possibility of extinguishing 80 per cent of the fires originating from engines in the air. It was accordingly requested that R.A.E. should be asked to outline their proposed schemes for the various aircraft types of this Command and to give a firm estimate of the weight of each installation so that a decision could be made as to whether the increase in weight could be tolerated. It was recommended that, in any case, the proposed automatic device, which would indicate the presence of a fire and carry out the correct fire drill on pressing the extinguisher button after a fire warning, should be incorporated at once in all aircraft since it did not involve the addition of any substantial weight. It was further recommended that immediate action should be given to the following points of engine installations:-

(a) Feathering pipes should be run so that the common mechnical failures would not cause damage to the pipes.

(b) Feathering pipes, fire extinguishing pipes and C.S.U. controls, from the fire proof bulkhead forward, should be made fire proof, i.e. of steel or tungum.

(c) Fire warning switches should, if possible, be flame operated and <u>not</u> heat operated.

(d) Fuel cocks should be at the rear of the fire proof bulkhead.

A reply dated 12 July 1943 was received from the Air Ministry stating that the M.A.P. had been requested to investigate the possibility of meeting the above-mentioned requirements. It was also stated that satisfactory progress was being made with the nitrogen installation.

A further reply dated 6 August 1943 gave particulars of the additional weight which would be involved by the installation of the improved fire fighting equipment, and stated that with the approval of A.C.A.S.(TR) arrangements for the appropriate modifications had been put in hand, giving first priority to heavy bombers followed by the Wellington. This letter was followed by another one dated 11 September 1943, pointing out that the weight involved in the installation of the following fire prevention and extinction equipment in heavy bombers would be approxomately 700 lb. made up as follows:-

(a)	Nitrogen equipment	300 ± 10 lb.
(b)	Methyl Bromide for engines (estimated)	170 - 200 lb.
(c)	Methyl Bromide equipment for fuel tank bays (estimated)	200 lb.

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In view of this considerable weight the Command was requested to give careful consideration to the possibility of deleting other items of equipment in order that it would not be necessary to reduce either the bomb or fuel loads. In reply it was, however, pointed out by this Headquarters that the Command had made recommendations earlier in the year for the removal of certain items of equipment, and in view of this it was difficult to suggest what further reductions could be made without resorting to the removal of equipment that was at that time considered necessary, or alternatively re-designing the aircraft or its components.

D.O.R. sent a further communication to this Headquarters on 2 November 1943, stating that it had been found that the weight of the Methyl Bromide equipment for fuel tank bays would be approximately 300 lb. and not 200 lb. as previously stated, so that the total weight would be approximately 500 lb. The Command was therefore invited to state whether this additional weight could be accepted for the three heavy bombers, before the M.A.P. was instructed to proceed.

It was pointed out by O.R.S. that it was D.O.R. who initiated the requirement for protection of the tank bays, and that we had no knowledge as to the efficiency of the proposed system under full-scale conditions. It was suggested, therefore, that before we asked for its introduction we should obtain from D.O.R. a statement as to its probable efficiency. If this was found to be high it was considered that the additional weight could be tolerated. The improved engine fire extinguishers were understood to have a good chance of success, and it was felt that these would contribute largely to the safety of our aircraft.

A reply embodying the above points was sent by S.A.S.O. to D.O.R. on 16 November 1943. In January 1944 D.O.R. provided some information on the efficiency with which the Methyl Bromide fire extinguisher system for tank bays might be expected to operate. It was stated that there seemed little doubt that the scheme was an extremely efficient method of dealing with tank fires, and that in the 23 experiments carried out in an approximately half-scale (steel) model of a Lancaster wing section, there was only one case where the fire was not extinguished. In this case the failure was due to a circumstance which would not operate in the air. The Command was therefore asked to consider the possibility of deleting such items as engine armour in favour of the introduction

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of the Methyl Bromide equipment for fuel tanks. There followed much discussion in this Headquarters, together with correspondence with R.A.E., during the course of which it was suggested by O.R.S. that the self-sealing should be deleted from the outboard tanks of the Lancaster to pay for the increased weight of the extinguishers as we were opposed to the deletion of engine protection.

Objections were raised to this by M.A.P. on the grounds that it would impair the efficiency of the Nitrogen system, but suggestions were put forward by O.R.S. indicating how this risk might be obviated even though the self-sealing was deleted. However, although it was ultimately decided by this Headquarters, after reference to Groups, that the self-sealing should not be deleted, it was agreed after an impressive full-scale demonstration of the tank extinction apparatus on 18 April 1944 that it should be incorporated on high priority. Unfortunately, no aircraft equipped with either the tank bay extinguisher system or the improved engine fire extinguisher system were delivered to the Command before the end of the war.

There were also unexpected delays in the introduction of the Nitrogen system into the production line of the heavy bombers in spite of the fact that the work was to be on the highest priority, and frequent reminders of the fact were supplied by this Command. Various dates, some as early as September 1943, had been advanced by M.A.P. as the date for commencement of embodiment of the modification into the production line, but the system had not materialised by the end of the year. In December 1943 it was found by R.A.E. that the vent valves proposed for the system might stick in severe icing conditions when nitrogen was not in use, and they considered that the simplest way of ensuring safety was to maintain the vent valves at temperatures above 0°C. They believed this to be possible when the valves were located behind the bulkhead in the engine nacelle, although they might freeze in the positions previously considered suitable.

In view of the shortage of aircraft at R.A.E. on which to make temperature measurements to settle the matter, this Section was requested by R.A.E. to arrange for the experiments to be done on an aircraft of this Command. We accordingly arranged for a Lancaster and Halifax to be detached to R.A.E. for the purpose, and it was found that considerable advantage was to be derived from the re-positioning of the vent valves. Owing to the risk of freezing of the Mark IV vent valves, a Mark VI valve having a rubber snifter disk was developed by R.A.E. to overcome the danger.

The first aircraft to be equipped with the Nitrogen system in this Command operated in April 1944 (although there were only very few aircraft so equipped at the time), but it was found that the Mark VI (modified) valves were unsatisfactory as the rubber used in their production became wrinkled on exposure to petrol, thus allowing nitrogen to escape. In addition it was found that the soldering of some of the connections on the Halifax was unsatisfactory; accordingly, a postagram was sent by this Headquarters on 6 June 1944 instructing units to discontinue use of the system until further notice. However, on 23 June 1944, a further instruction was sent by the Engineer Branch to all units indicating that tests had shown that with the Mark VI valves fitted nitrogen pressure might be held for some 2-3 hours, so that some protection would be derived from the use of the system. In view of the fact that the weather conditions under which the Mark IV valves were likely to freeze were unlikely to be met until the end of September, the Mark IV valves were to be fitted until that time. Authority was given to Groups to use the system with the Mark VI valves until Mark IV valves were available if they so desired. If the system was used, flight engineers were to turn on the system as soon as the aircraft was airborne and to record pressures every half-hour until the pressure fell to 50 lb/sq.in.

Satisfactory vent valves had not been supplied by the end of September, and the question was raised as to whether aircraft should be allowed to continue to operate equipped with Mark IV valves. In view of the fact that there had been comparatively few reports of icing conditions in August and September, and that during that period over 90 per cent of the nitrogen filled sorties had landed with nitrogen unexhausted, it was recommended by this Section that:-

(a) The risk of freezing in flight should be accepted.
(b) Vent valves should be removed from all unserviceable systems in view of possible danger.

These recommendations were implemented in an Engineer Branch letter dated 23 October 1944. In December 1944 a preliminary analysis of the effects of the Nitrogen system was carried out and it was found that the value of the system was apparently small, but owing to the very poor quality of the reporting and the low serviceability of the system, considerable doubt attached to the result. Further attempts to assess the effectiveness of the Nitrogen system were made, but it proved impossible to obtain a conclusive answer owing to the very large number of cases in which it was not known whether the system was used, and even in cases where it was stated to be used whether it was in fact serviceable.

At the end of November 1944 a request for information regarding the frequency of fire in missing aircraft had been received from D.P.A., and a letter was sent to Air Ministry showing that about 80 per cent of our missing aircraft were lost in flames and giving details, based on a rather small sample, of the locations of these fires.

In response to a request for our views on the desirability of producing a non-inflammable hydraulic fluid, we stated in January 1945 that it seemed likely that some 10 per cent of our losses were due to fires in the hydraulic system, and it therefore appeared highly desirable to develop a non-inflammable fluid if hydraulic systems were to be retained. It was, however, pointed out that in our view it would be far preferable to substitute electrical systems for the hydraulic systems.

It appeared from reports of aircrew who had been involved in fuselage fires in the air that the hand extinguishers provided were of limited use in quelling such fires, and in April 1945 the R.A.E. carried out trials to test various types of hand extinguishers. These trials were attended by representatives of Bomber Command O.R.S. and during the course of discussion it was suggested that a great improvement in the performance of existing extinguishers could be achieved by increasing the discharge rate of the extinguisher. It was found that extinguishers Type No. 5 were virtually useless. A minute was sent to O.R.(Eng.) on 21 April recommending the immediate modification of all Type No. 3 extinguishers and the deletion of Type No. 5 extinguishers unless their performance could be improved. These recommendations were passed to Air Ministry by O.R.(Eng.) in a letter dated 1 May 1945.

It will be seen from the foregoing that although it was early realised and pointed out by this Section that the fire risk was the major hazard associated with the operation of bomber aircraft, and although the experimental establishments took energetic steps to develop remedial measures, the war closed with fire prevention apparatus in much the same state as it began, and that due to the inevitable delay in introducing the necessary modifications into the production line Bomber Command lost very many more aircraft and crews than would have been the case had the fire hazard been appreciated earlier, or had it been possible to take prompter action once it had been recognised.

/ Research

Research into 'Phenomena seen at Night'

Another investigation which was in some ways connected with the risk of loss of an aircraft by fire was undertaken in September 1942. Crews had reported encountering strange pyrotechnic devices over Germany, and there was a certain amount of apprehension as to the purpose of these devices.

A tour of investigation in which aircrews and intelligence officers in Nos. 3 and 5 Groups were closely questioned was undertaken, and the results were published in a report entitled 'A Note on Recent Enemy Pyrotechnic Activity over Germany'.[(1)] It was found that there were at least two different phenomena which had, unfortunately, often been reported by the same name 'Chandelier Flares'.

(a) These objects appeared in the sky in heavy concentrations of flak and from a distance appeared very similar to aircraft falling in flames. They were given the name of 'Scarecrow Flares' and were shown to be quite harmless. There had previously been considerable apprehension among crews lest these objects were some form of aerial mine, and this report did much to allay their fears.

(b) The other phenomenon was considered to be purely to assist fighters, and was designated 'Fighter Flare'.

At about the same period there had been many references to 'Flashless Flak', and as a result of this investigation its existence was thought to be doubtful; it was shown that, even if it did exist, it exhibited all the normal characteristics of flak except the brilliance of the flash. Similarly, the suspicions, aroused by enemy propaganda, that they were using aerial minefields were shown to be groundless.

It is considered that the above-mentioned report based on a comparatively short but very searching enquiry did much to protect the morale of aircrews by the prevention of ill-considered speculation as to the nature of various phenomena reported by crews at interrogation.

Damage to Aircraft by Falling Bombs

With the increase in concentration of our raids which began to be achieved in the early part of 1943, new dangers to our aircraft presented themselves. The chief of these were the risks of collisions and of being struck by bombs released from aircraft at greater altitudes. The risk of collision and the probability of being hit by falling bombs is discussed elsewhere. It is appropriate here, however, to consider the vulnerability of aircraft to the impact of bombs.

(1) O.R.S. Report No. 53. (A.H.B./II/39/1).

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A careful study was made of the damage sustained by all aircraft which returned to this country after having been struck by falling incendiary bombs during the first five months of 1943, and it was found that the bombs had ignited in only a few cases and that the damage caused was in general purely due to the impact of the bombs on the aircraft. It is noteworthy that the crews were very often unaware that their aircraft had been struck by bombs and attributed the damage (as did many of the engineer officers who examined the aircraft on return) to flak.

A composite plot of the positions of all the bombs striking our aircraft was made on drawings of each of the heavy bombers, and it was found that there was no area exhibiting a marked paucity of strikes indicating that there were no singularly vulnerable spots. It appeared likely, however, that an incendiary bomb could cause the loss of an aircraft by:-

(a) Killing the pilot.
(b) Severing the main spar boom.
(c) Causing the loss of large quantities of petrol.
(d) Causing the loss of large quantities of oil.
(e) Striking an engine.
(f) Severing controls.
(g) Starting a primary fire in a position where it could not be extinguished by the crew.

A rough examination of the plan drawing of a Lancaster indicated that rather less than one-half of area should be counted as vulnerable to damage by incendiary bombs and it was considered not unreasonable to assume that only 25 per cent of the strikes on those areas were lethal, so that it appeared that of the order of 1 in 10 of the bombs striking an aircraft were lethal and hence about 0·05 per cent of sorties despatched during the first five months of 1943 were lost as a result of damage by falling bombs. The loss rate from this cause was therefore small compared with that due to other causes, and could only be decreased by reducing the concentration over the target which would have led to a disproportionate increase in losses due to flak.

Even after the publication of this paper there continued to be some anxiety among aircrews, and at this Headquarters concerning the danger to aircraft from falling bombs, and it was felt desirable by O.R.S. to carry out some experiments to test our belief that the bombs only caused the destruction of our aircraft in a small percentage of cases. A request was accordingly sent to M.A.P. that experiments should be carried out to find the effects of a 4 lb. incendiary

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bomb entering a petrol tank under various conditions of tank contents and bomb velocities. It was considered by M.A.P. that it would be a matter of great difficulty to carry out fully representative trials owing to various experimental limitations obtaining at the Research stations. However, it was felt by O.R.S. [redacted] that a sufficiently good estimate of the risk could be obtained by subsidiary experiments, and it was agreed that these should be carried out.

These experiments fell into two parts:-

(a) Firing both live and inert bombs through a mock-up petrol tank in a wing structure. The tank contained an explosive petrol-air mixture but no liquid petrol. This section of the work was carried out at the Road Research Laboratory (R.R.L.).

(b) Initiating live bombs both above and below the surface of the fuel in a bath of petrol. This part of the experiment was carried out at Orfordness.

The R.R.L. experiments showed that even when the bomb was fired at its terminal velocity through the mock-up tank structure, the petrol vapour was not ignited. Further, it was shown that the resistance afforded by the dural plates and self-sealing tanks which would be encountered in the wing of a heavy bomber was insufficient to operate the fuse of the 4 lb. bomb.

The Orfordness trials showed that if a 4 lb. incendiary bomb enters a bomber wing fuel tank without making a large entry hole, and is initiated below petrol level, the fire will, in general, be extinguished by the petrol provided that the petrol is not shallow enough for the bomb flame to reach the surface of the petrol. If the bomb is initiated above petrol level.and dropped into the tank, a fire is probable.

These two trials showed conclusively that our views regarding the risks of fire in tanks were justified, and it is of interest to record that shortly after the experiments were carried out a Lancaster returned with two bombs lying immersed in petrol in one of its main tanks.

A careful watch was kept on later reports of 4 lb. and 30 lb. bombs striking aircraft, but no grounds for altering our opinions on the hazards associated with them came to light. There were cases towards the end of the war of 500 lb. and 1000 lb. bombs striking our aircraft, but these were not numerous enough to warrant any change of tactics to minimise the frequency of such occurrences.

/ Casualties

Casualties to Personnel Directly Due to Enemy Action

In addition to the studies relating to the aircraft as a machine, [redacted] O.R.S. [redacted] carried out researches into the frequency with which enemy missiles struck members of the crew. In the first instance the information was used to obtain a measure for the accuracy of reporting of damage to the aircraft. It was known that injury to crew was very faithfully recorded, and by a comparison of the vulnerable area of a man with the total area of an aircraft it was possible to deduce a figure for the percentage of flak holes reported. It was concluded that for data covering the last few months of 1942 'The agreement between expected and observed numbers of casualties to personnel suggests that the reporting of the number of aircraft damaged by flak is fairly complete, and that the figure obtained for the average number of fragment strikes is approximately correct'.

In February 1943, a report entitled 'Casualties among Aircrew Personnel directly due to Enemy Action on Night Operations' gave detailed statistics of the frequency of injury and the severity of wounds sustained in the various crew stations during the summer and autumn of 1942.[1] It was shown that very few members of aircrew sustain injury directly as a result of enemy action, compared with those sustaining injuries from other causes. (The term 'directly by enemy action' means in this case that the man concerned was actually struck by an enemy missile). During the seven month period considered it was estimated that not more than six aircraft were missing purely as a result of death or severe injury of the pilot.

It appeared from the data considered to be a rare occurrence for navigators and wireless operators to be called upon to man a turret as a result of the death or injury of the normal gunner. In addition, the frequency of injury to pilots was so low that it was a matter for consideration whether it was economic to carry a second pilot, and whether even the labour of training a pilot's assistant was justified. The carrying of a second pilot except for training purposes was discontinued a short time before the publication of the report, but it was decided to continue the training of a pilot's assistant as it was felt that it was desirable that the pilot should be able to leave his seat, even on occasions when he was not wounded. It was decided to abolish air gunner training for navigators,

(1) O.R.S. Report No. S.77.

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flight engineers and wireless operators except that air gunner's training continued to be given to wireless operators to be employed in light bombers.

At the end of 1943 the problem of assessing the potential value of body armour was exercising the minds of Air Ministry (D.Arm.R.), and [redacted] O.R.S. was asked to produce a further paper on casualties to aircrew making special reference to the probable value of body armour. A report entitled 'A further note on Casualties among Aircrew Personnel directly due to Enemy Action on Night Operations'(1) was published in January 1944, and this gave data covering the year ending 30 November/1 December 1943. It was shown that the frequency of direct enemy action casualties among aircrew personnel was very small and had remained unaltered by the removal of the main armour bulkhead. It was estimated that the use of the American type of flak jacket would only be effective in preventing about 50 moderate or slight casualties per 50,000 sorties, and in view of its weight with the fatigue it would produce, would be likely to do more harm than good. Similarly, it was estimated that the flak helmet would have prevented only about 50 head injuries during the year, but that it might be justified if aircrews expressed a wish to use it, provided that it was not too heavy and cumbersome and did not induce fatigue. It was thought doubtful, however, whether the reduction in casualties, most of which were in any case only slight, would merit the labour involved in the production of the helmet. Largely as a result of this paper it was decided not to proceed with the supply of body armour to the R.A.F. bomber crews.

The advent of daylight operations in 1944 with the higher number of aircraft damaged by flak made it desirable to carry out an analysis of casualties for daylight operations which took place in the summer and autumn of 1944. The analysis, of which the results were not published, showed that there was no difference between the figures for casualties per aircraft damaged by day and by night, so that there was not a case for carrying body armour in R.A.F. Bomber Command aircraft, even on daylight operations.

Investigations into Expenditure of S.A.A. by Air Gunners

The disposable load of an aircraft is limited, and consideration always has to be given to the distribution of this load between equipment, fuel, oil etc,

(1) O.R.S. Report S.120. (A.H.B./II H/241/22/14).

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and offensive load such as bombs. There was stowage capacity for a very considerable load of S.A.A. amounting to 18,000 rounds (over 1000 lb. weight) in heavy bombers, and in June 1942 O.R.S. was asked to carry out an investigation into the frequency with which various guns were used and the amount of ammunition fired in combat.

At the time there were no data in the Headquarters from which the information could be extracted, and it was necessary to get some interim figures from Groups and to take steps to improve the reporting on Combat reports of ammunition fired in combat. By March 1943 a sufficient volume of data had been collected on the subject to make possible a statistically significant analysis, and the results were published in a report entitled 'Ammunition fired in Air-to-Air Combats at Night by Bomber Aircraft'.[1] The analysis showed that 1,000 rounds for the mid-upper-turret was sufficient for 99 per cent of combats (the average was 235 rounds) and in the case of the rear turret 2,000 rounds was sufficient for 99 per cent of combats, 1,100 for 90 per cent and 550 for 75 per cent.

It was pointed out that a useful saving in weight could be obtained by restricting the amount of ammunition carried for use by the rear turrets of all heavy bombers engaged on night operations to 3,000 rounds (the stowage capacity for this turret was 10,000 rounds), which would allow a reasonable margin above that required for combat for gun warming and testing. It was recommended, however, that the stowages for larger capacities should be retained in view of the possibility that the aircraft might meet with changed conditions at a later date.

The figures quoted in Report No. 68 referred mainly to medium bombers, although some figures for heavy bombers were quoted and it was felt desirable to carry out a further analysis on similar lines at a later date. This analysis, covering the period of 12 months ending in February 1944, was undertaken early in 1944 and the results were published in a report entitled 'Ammunition fired in Air-to-Air Combats at Night by Heavy Bomber Aircraft'.[2] It was shown that the average number of rounds fired per combat was approximately the same for the two periods analysed, and that the amount of ammunition suggested in the previous report would have been sufficient for all but four of the combats during the year.

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(1) O.R.S. Report No. 68.
(2) O.R.S. Report No. 98. (A.H.B./II/39/1).

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In April 1943, R.A.E., who had asked O.R.S. for data in connection with an investigation they were doing into gun blast, were given the information that it was estimated that at that period the average life of a heavy bomber was something of the order of 20 sorties and that during that life there was about 1 in 4 chances that the aircraft would be engaged in combat with an enemy fighter. The guns would of course also be fired for gun warming and testing and 20 to 30 rounds per gun per sortie would probably be fired for these purposes.

Analysis of Crashes not due to Enemy Action

In January 1942 it was suggested by Air Ministry that the percentage of night sorties resulting in crashes and forced landings in Bomber Command during the latter part of 1941 was higher than it was during the corresponding period of 1940, and O.R.S. was asked by the Air Staff to make an examination of the matter to ascertain whether the allegations were correct and if so to ascertain the causes.

An analysis of casualty signals and of the Daily Summaries of Crashes and Forced Landings prepared by the Training Branch was carried out and the results were published in a report entitled, 'Preliminary Note comparing number of casualties not due to Enemy Action on Operational Sorties during October - December 1940 and 1941'.(1) It was found that much of the information relating to causes of crashes in 1940 had been destroyed, but from the sample available it was shown that all types of aircraft showed a greatly reduced casualty rate in 1941 from that obtaining in 1940 with the exception of the Wellington which showed a slight increase. Details as far as they were available of all causes of crash were given and it was shown that engine failure, fuel shortage, overshooting and bad landings were the causes individually responsible for more accidents than any other.

The tentative results produced by this analysis proved to be of such general interest that it was decided to carry out a more detailed analysis covering the period June 1940 to December 1941, and the results were published in a report entitled 'An Analysis of Casualties not due to Enemy Action on Night Operational Sorties during June 1940 - December 1941.(2) It was shown that the accident rate of the Whitley per 100 sorties was rather higher than that obtaining for other

(1) O.R.S. Report No. 28.
(2) O.R.S. Report No. S.43. (A.H.B./IIH/241/22/14).

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types, and that aircraft which had a high accident rate had a high missing rate, indicating, as one might expect, that losses from all causes of an aircraft which is readily handled are less than those of an aircraft more difficult to handle. The principal cause of accident, in approximate order of seriousness, were:-

(a) Fuel shortage.
(b) Bad landings.
(c) Engine failure.
(d) Taxying and take-off mishaps.
(e) Flight into ground.

Over the eighteen months considered bad weather was a contributory cause in at least 25 per cent of all accidents, and fluctuations in the monthly accident rate could largely be accounted for by variations in weather conditions. As a result of this report a letter was sent to all Groups calling attention to the wastage occurring not due to enemy action, and pointing out that about 70 per cent of all crashes resulting in Cat.B or Cat.E damage were due to:-

Fuel shortage	-	26 per cent
Landing accidents	-	24 per cent
Engine failure	-	18 per cent

It was urged that every effort should be made to reduce this wastage. Further, both the Training and Navigation branches at Command Headquarters intensified their investigations into accidents due to fuel shortage with a view to reducing accidents from this cause.

<u>Analysis of the Frequency of use of Fuel Jettison Apparatus</u>

At the end of 1942 there was considerable interest in the problem of reducing weight on bomber aircraft, and among other items under consideration was the fuel jettison system. O.R.S. was accordingly asked to investigate the frequency with which the apparatus had been used and in what circumstances, so that an estimate could be made concerning the desirability of retaining it on bomber aircraft. The results of the analysis which covered the period July to December 1942 (inclusive) are set out in Bomber Command O.R.S. Report No. B.120.

It was thought that there were probably three conditions under which it might be essential to jettison fuel:-

(a) Preparatory to ditching.
(b) In severe icing conditions, if after jettisoning bombs it is not possible to maintain height.
(c) After engine failure, if after jettisoning bombs it is still not possible to maintain height.

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It was shown that it is necessary as a general rule for aircraft to float for about two minutes after ditching to ensure that all members of the crew alive and not seriously injured should be able to abandon aircraft, but there appeared to be a negligible correlation between the time the aircraft floated and the amount of petrol on board, so that on that score there was no justification for the retention of the jettison system. The analysis also indicated that a total of about four Stirling aircraft might possibly be saved per year as a result of being able to jettison fuel, but that in all cases of jettisoning fuel by other types of aircraft during the period under consideration, the same result could have been achieved by jettisoning bombs.

The criterion, therefore, for deciding whether the fuel jettison apparatus was a requirement could be obtained by balancing the labour required to build four Stirlings and to train their crews against that required to fit and maintain fuel jettison gear in all the aircraft of the Command. It was eventually decided, after reference to Groups, not to delete the fuel jettison gear from Lancasters and Stirlings, although it had already been removed without ill effect from Halifaxes to improve their performance.

CHAPTER 20

EFFICIENCY AND MANPOWER PROBLEMS

Introductory Survey

Scientific methods and techniques are not so obviously applicable to the study of organisational matters as to investigations of, for example, bombing accuracy or the operational efficiency of radar equipment. This seems the most probable explanation why research into organisational matters was not initiated until somewhat later in the European war than research into most other topics with which the R.A.F. Operational Research Sections concerned themselves. By the time administrative research began to be undertaken seriously shortage of manpower had become the major factor limiting the expansion of the Air Force and, so, much of this kind of research was directed towards saving manpower. And in particular, partly because the study of maintenance work lent itself to the scientific approach, partly because early success attended research work into means of securing maintenance manpower economy but mainly because maintenance personnel were so important in affecting directly the amount of flying that could be done, a good deal of the administrative research effort was devoted to the Aircraft Servicing Organisation and maintenance manpower problems.

Serious scientific study of organisational matters began in Bomber Command from a careful perusal of a Coastal Command O.R.S. report on 'The Efficient Utilisation of Manpower with Special Reference to Maintenance Manpower'.(1) This report pointed out the influence on maintenance manpower economy of the irregularity with which in varying degrees any programme of flying was bound to be carried out. If a unit was manned to meet peak loads, then it was likely to be capable of a greater output given a uniform rate of supply of work. A scheme was suggested for careful control of 'in-use' aircraft on 'fit-for-flying' days so that a unit's capacity for flying would be exhausted only when bad weather or lack of opportunity eliminated the possibility of flying in any case and so that the rate of arising of unserviceability would ensure a supply of work to the maintenance organisation throughout periods of no flying. Since irregularity was a notable characteristic of the Bomber Command task, it was not unreasonable to

(1) Coastal Command O.R.S. Report No. 206 dated 15 November 1942.

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hope that the Coastal Command O.R.S. proposals would be applicable. A great deal of thought was devoted to considering how to evolve such a scheme of 'Planned Flying and Planned Servicing' for Bomber Command but the Command Air Staff was not prepared to accept the restrictions on their operational freedom which the adoption of any such scheme was likely to involve.

Since the planning of flying to even out the servicing load was out of the question, the next step logically was to examine ways of organising the servicing personnel so as best to meet a fluctuating programme of work. This was, in fact, the line of development which research into maintenance manpower economy by Bomber Command O.R.S. now took. By examination of statistical records at unit, group and command level a body of data was carefully built up on the internal workings of various sections of the servicing organisation. From this a quantitative estimate was made of the manpower 'wastage' which could be attributed to irregularity in the in-flow of work. It was pointed out that centralisation and pooling of work could do much to remedy this loss and various changes in organisation were examined to this end. The formation of Group Initial Fitment Depots, the pooling of ground crews, the pooling of maintenance flight personnel and a change in the balance of resources by the addition of aircraft, aircrews and specialist maintenance personnel were recommended. This would result in a considerably increased flying output with no overall increase in maintenance manpower backing. These recommendations were in agreement with the recommendations for a Base Organisation which had meantime been evolved independently by the Engineer Branch. The mutual support which the O.R.S. and the Engineer Branch lent to one another's recommendations led to the adoption of the Base system in Bomber Command.

As a further result of these investigations Bomber Command O.R.S. had become familiar with the details of the workings of the servicing organisation and had gained an insight into associated problems which enabled it to advise on such matters as the relative merits of 2-flight and 3-flight squadrons. An essential background was also thus provided for the ensuing investigations, undertaken at the request of Command Staff, into the correct value under various conditions of the aircrew/aircraft ratio. The object of these investigations was to discover how the resources of aircrew and aircraft should be balanced to ensure the availability of one fit crew to man each serviceable aircraft when the opportunity

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for large-scale effort arose. Since the level of aircraft serviceability depended very much on the supply of maintenance manpower and since both crew fitness and aircraft serviceability depended on the pattern and intensity of effort, the relationship between this and the earlier work was a close one. The achievements of this new work were the determination of the correct aircrew/aircraft ratio and of the need for its modification from time to time and, of more fundamental importance, a contribution to the theory underlying the relationship between the numbers of aircraft, aircrew and maintenance personnel in operational units and the flying performed by the units.

In the course of the work on the aircrew/aircraft ratio a scheme was evolved for keeping a graphical check on the balance between each unit's resources of aircrew, aircraft and maintenance personnel. Although this system was not adopted in practice, it is of interest in foreshadowing later work, undertaken when, in view of the manpower situation, the policy was laid down by the Air Ministry that Operational Research Sections should be encouraged to investigate the relationship between flying output and the level of maintenance manning. The investigation thus initiated was bound up with earlier work on the planning and organisation of servicing support for the flying effort not only through the intermediate work on the aircrew/aircraft ratio but also directly. Indeed the object of the investigation was the development for Bomber Command of a system corresponding to 'Planned Flying and Planned Servicing' in Coastal Command but without the latter's limitations on operational freedom. Some new factors affecting the flying effort were unearthed in the course of this work and fresh light was thrown on the effects of other known factors. A system was devised of periodically reviewing each unit's flying effort in relation to its resources of men and equipment and on this basis adjusting, whenever necessary, to a more economical distribution of resources. Since a proper trial of this scheme was prevented by the end of the European war, its utility must be regarded as not proven. In any event the information which it was designed to provide is really essential to a proper planning of resources and such a scheme is likely to be a basis for future planning of support for any flying effort in which a very large measure of operational freedom is indispensable.

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The work mentioned so far has dealt with matters of general organisation and the problem of how best to meet the programme of work necessary to support a given flying effort. Research was also undertaken to find means of reducing the actual volume of work associated with a given amount of flying. Suspicion voiced in a report by Coastal Command O.R.S. that more time was being spent on inspections than was justified by the decrease in repairs and failures which the inspections brought about, led to a Bomber Command O.R.S. investigation into the number of and manhour expenditure on repairs to an aircraft at various stages after the minor inspection. This work led to a 50 per cent increase in the flying hour interval between minor inspections and made possible the equivalent in manpower economy of 10 per cent of personnel in Repair and Inspection Squadrons.

In order to arrive at a satisfactory conclusion on the question of minor inspection periodicity, it was necessary to have detailed information about the manhours absorbed on various servicing tasks. This information could not be supplied with the accuracy or in the detail required by the units themselves but had to be obtained through the agency of a special party of technical personnel who recorded the work done on all the aircraft in one unit in the necessary detail. This is but one example of the need that existed for some means of discovering various details relating to the functioning of Station organisations. Owing to the fact that units were normally under establishment, particularly in the administrative posts, technical personnel had to be mis-employed on miscellaneous duties, and greater numbers were consequently established than were required to undertake the technical duties only. By 1944 it had become evident that the rationalisation of Station duties and the elimination of unnecessary tasks were long overdue, and it seemed likely that there was a considerable waste of manpower on such duties. Accordingly, in order to ascertain to what extent manpower was being wasted on unnecessary Station duties and the extent to which the establishment of technical and administrative personnel could be adjusted, recording parties were formed to observe the state of occupation of the personnel in selected stations in various Home Commands. For a considerable period, before centralisation of control under D.D. Science at the Air Ministry became desirable, each party worked under the scientific control and general

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supervision of the Operational Research Section of the Command in which it was operating. The results obtained enabled the O.R.S. to provide its Command with information on the amount of time expended at units on various activities and to advise on a number of matters connected with Station organisation, for example, on the size of a gang or section appropriate to carry out a given task such as, say, building power plants. From the more long-term view, information, forwarded in digestible form to the Air Ministry could be translated into figures to illustrate manpower potentialities and serve as a basis for provisioning purposes, as, for example, for the forecasting of future total establishments, trades and training capacity. In particular, a recording party working in Bomber Command obtained important information on the detailed working of a new servicing system, the so-called Marston Moor Servicing Scheme.

In addition to the full-scale investigations which have been seen to fit in with a process of fairly logical development, Bomber Command O.R.S. took a number of smaller items of work mostly in order to answer specific questions such as 'How many men are required to service the Fairey Mark I "Window" Launcher?' or 'How many aero-engines are required per month to back a given operational programme under specified conditions?' While these problems did not fit in very well with the general scheme or work, their solution was often made possible or more complete by the background of knowledge provided by the general work.

Thus, administrative research at Bomber Command during the war, while it certainly did not exhaust all possibilities, covered a comprehensive field. Starting towards the end of 1942 with research into the general problems of planning and organising servicing support for the flying effort, background theory was built up for studying and insight acquired into the working problems of R.A.F. organisation. Supported by detailed information, acquired by recording parties, on working conditions and utilisation of manpower at unit level, this work enabled Bomber Command O.R.S. to advise R.A.F. staff, Bomber Command, on such matters as the Base Organisation and the relative merits of 2-flight and 3-flight squadrons, and assisted in the solution of a number of miscellaneous problems which the R.A.F. staff presented to Bomber Command O.R.S. from time to time. The individual pieces of work, which were most successful, were undoubtedly the determination of the aircrew/aircraft ratio and the

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research into the optimum flying-hour interval between minor inspections. The usefulness of the latter piece of work is directly measurable since it led to a 50 per cent reduction in the periodical inspection load on Servicing Wings. Other work, for example, that on the development of a scheme for the statistical control of resources, was less obviously fruitful but resulted in a fuller understanding of organisational issues. Further, some system of centralised control of resources or, at least, the relating of flying achievement to the number of men and quantity of equipment needed to back that achievement is certain to find a place in any future administrative research programme.

The Organisation and Planning of Servicing Support

With an increase in aircraft production it became evident in 1942 that the supply of manpower was to displace the supply of aircraft as the controlling factor which determined the upper limit to the operational effort of Bomber Command. It was important that every possible means of ensuring the efficient use of maintenance manpower should be explored. There was, therefore, considerable scope for research into the various factors affecting operational effort and, more particularly, into the relationship between operational effort and maintenance manning.

The first problem of this nature undertaken by Bomber Command O.R.S. arose from the question whether sending out a small force of aircraft frequently or sending out a large force of aircraft less frequently would result in the greater overall effort over a long period. Bomber Command O.R.S. was asked to study the manner in which serviceability varied with the number of sorties despatched in a given time and to report on which of the two policies, of making frequent small-scale efforts or less frequent large-scale efforts, was more conducive to maintaining a high level of serviceability. The interest of this investigation lies solely in the fact that it was the first approach to the general problem in Bomber Command.(1) The results of the investigation were of little significance since a high serviceability was neither a desirable end in itself nor a reliable indication of efficient utilisation of resources: for example, 100 per cent serviceability might be easily obtained by a unit which did no flying.

(1) 'The Efficient Utilisation of Manpower Resources with Special Reference to Maintenance Manpower'. Coastal Command O.R.S. Report No. 206 dated 15 November 1942.

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Serious interest in the economics of flying as a scientific study was aroused at Bomber Command for the first time by the publication of a Coastal Command O.R.S. report on the efficient utilisation of maintenance manpower.(1) This paper contained the first scientific analysis made of the organisation behind the flying effort and laid down basic principles governing the efficient working of that organisation. The most significant point about the paper was, perhaps, its explicit recognition that in all flying, and particularly in operational flying, periods of intense flying activity were inevitably sandwiched between periods of no flying, the duration of which would depend on the weather and the need for flying to be done. Coastal Command O.R.S. introduced a classification of squadrons according to the regularity of their effort: the most important classes were as follows:-

(a) Constant Effort Squadrons (on the so-called 'Semi-Saturation Cycle') whose fairly regular effort was subject to minor fluctuations due to weather and other factors.

(b) Variable Opportunity Squadrons which had comparatively frequent opportunity but somewhat irregular effort.

(c) Fleeting Opportunity Squadrons which were required for infrequent and unpredictable periods of intense activity.

Under the ideal conditions of a perfectly regular flying effort the rate of flow of work to the ground staff would be uniform and the maintenance establishment should correspond to the amount of flying done. But under any practical conditions the rate of arising of work would vary in sympathy with irregularities in the flying. Consequently there were likely to be periods when the ground staff were not fully occupied and other periods when they were working to capacity and, in that event, the actual output from maintenance personnel would fall below their potential output given adequate work at all times. Under these circumstances the maintenance establishment required would not strictly correspond to the amount of flying done but would be influenced by the pattern of the flying effort. It was desirable by eliminating periods of slackness to make the maintenance establishment correspond to the mean monthly flying effort and so save manpower. In other words, the problem presented itself of finding a means of providing the maintenance personnel with an even flow of work.

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(1) 'An Investigation into the Effect of the Size and Frequency of Operations by Individual Squadrons on the Maintenance of Aircraft Serviceability'. Bomber Command [redacted] Memo. No. 32 dated 25 November 1942. (A.H.B.2 unindexed).

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The Coastal Command solution to the problem of achieving a smooth flow of work was to fly during periods of activity a number of sorties somewhat in excess of the daily average necessary for the completion of the task. This would result in aircraft becoming unserviceable at a greater rate than the maintenance personnel could deal with them. The extra flying would be 'turned off' when there were only sufficient aircraft to maintain the necessary daily average of flying or when it was considered that there were sufficient aircraft awaiting maintenance to keep the maintenance personnel fully occupied until the next burst of flying was permitted by weather conditions or other relevant factors.

The Operational Research Committee studied and considered the Coastal Command O.R.S. paper (1) on Planned Flying and Planned Maintenance (P.F./P.M.) as these principles came to be called, and it was decided that a study should be made of the possible applications of P.F./P.M. principles to the special problems of each Command. Logically, though not historically, the next step was the production of a paper containing the deliberations of a Coastal Command O.R.S. expert on the problems of Bomber Command. (2)

This paper analysed broadly various factors relevant to the organisation and planning of the Bomber Command flying effort and pointed out in this connection a number of matters requiring detailed investigation. The problem of planning Bomber Command operations was a complicated one. Weather restrictions on the number of occasions suitable for operations were particularly severe for this Command since suitable operational weather had to obtain not only at Base but also en route and at the target a considerable distance away. Again it was desirable to send out a large force on each operation in order to saturate enemy defences and minimise the wastage rate. These and other factors ruled out for Bomber Command the possibility of planned flying in the time-table sense and in the sense of limitation of in-use aircraft on particular days.

Nethertheless it remained desirable to estimate an optimum scale of effort for Bomber Command. This would depend largely on an already decided production programme which was capable of only limited alteration. Large irregularities

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(1) Coastal Command O.R.S. Report No. 206.

(2) 'Planned Flying and Planned Maintenance in Bomber Command'. Bomber Command [redacted] Memo No. 33 dated 14 July 1943. (A.H.B.2 unindexed).

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were introduced into the pattern of flying activity by the weather. When the weather was suitable it was desirable to operate a force large enough to saturate enemy defences but not so large as to 'overbomb' the target. Where, for example, an expansion of front line strength were contemplated at the expense of a temporary reduction in effort, it was necessary to weigh in the balance the relative values of devastating an industrial target at a given time, or say, six months later and the difference in the aircraft losses likely to be incurred in doing so at the two different times. The possibility of taking into account these and all the other relevant factors was remote but any studies completed would be of great value in removing implicit policy decisions and bringing to consciousness at any rate the nature of the policy implications inherent in any detailed steps.

With the Bomber Command effort thus determined, the next stage would be to determine the numbers of aircrew and of maintenance personnel required to support it. Some details of the problem of ensuring that crew fatigue limited operations on only rare occasions were discussed. On the question of servicing support the paper suggested that all maintenance manning with the exception of that for daily inspections should be on the basis of flying hours per month. Under the conditions of bomber operations, in which a certain amount of dead labour was inevitable, it would not be possible to reduce manning right down to the level corresponding to the mean flying hours per month regarded as a steady effort but centralisation and pooling of work could do much to absorb irregularities in the flow of work. Finally the division of resources to support the training effort required to back the operational effort would be determined. Any limitation of resources encountered in the course of these estimations would lead to a scaling down of effort and consequent readjustment of requirements for all resources.

An attempt had already been made to find a basis for establishing an operational task for Bomber Command as a starting point from which the economical employment of manpower could be studied.(1) The basic hypothesis was that the inflow of new aircraft should exactly balance aircraft wastage, thus maintaining a constant front-line strength. The number of sorties that could be flown in a

(1) Operational Effort based on Rate of Make-up of Losses'. Bomber Command O.R.S. [redacted] Memo. No. 34 dated 22 June 1943. (A.H.B.2 unindexed).

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month could thus be estimated from the production programme and the wastage rate, and the means of deploying manpower economically to fulfil this task could be investigated. This idea was not, however, acceptable to Command Staff.

It soon became clear that no scheme which involved laying down a definite flying task would be acceptable to the Air Staff at Bomber Command, which felt the danger of losing flexibility in the planning of individual operations. A line of development parallel to that detailed above was, therefore, of perhaps greater importance for this Command. Following the decision of the Operational Research Committee that the possible applications of P.F./P.M. principles to the special problems of each Command should be explored, representatives of the Bomber Command Engineer Staff, of Bomber Command O.R.S. and of Coastal Command O.R.S. met to discuss P.F./P.M. and manpower economy in general.(1) It was decided that a Bomber Command O.R.S. scientist should familiarise himself with the organisation and records of the Engineer Branch at Bomber Command, study the details of the revised maintenance records and organisational methods which had recently been introduced into Coastal Command and consider the application of these records or modifications of them to the work of Bomber Command, visit selected operational Bomber Stations for detailed 'fieldwork' and finally co-ordinate these researches into a scheme for the efficient utilisation of maintenance manpower. The results of these investigations are contained in a paper called: 'A Study of Maintenance Manpower in Operational Squadrons of Bomber Command'.(2)

This paper pointed out that, since the demand for an unrestricted and unpredictable maximum effort was a frequent operational requirement in Bomber Command, it was extremely doubtful whether planned flying, in the sense of a fixed number of aircraft on each fit-for-flying night, was applicable to its operational squadrons. It therefore proposed to deal with the steps which might be taken to enable the maintenance organisation to deal most effectively with the existing greatly fluctuating flying effort. For this purpose it divided the servicing personnel for separate consideration in the following four classes:-

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(1) 'The Efficient Utilisation of Maintenance Manpower'. Bomber Command O.R.S. [redacted] Memo.No. 35 dated 20 December 1942. (A.H.B.2 unindexed).

(2) Bomber Command O.R.S. [redacted] Memo.No. 36 dated 4 June 1943. (A.H.B.2 unindexed).

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(a) Ground crews, who comprised about 40 per cent of the maintenance establishment, were attached to and responsible for the day-to-day servicing of a single aircraft.

(b) Specialist workers, such as electricians, instrument repairers, wireless and R.D.F. mechanics, metal workers and armourers, who formed about 30 per cent of the establishment, went from aircraft to aircraft, inspecting and servicing the parts and appliances under their charge.

(c) The personnel of the H.Q. Maintenance Flight, who formed about 20 per cent of the establishment, undertook the lengthier repairs and servicing jobs, such as acceptance checks, initial fitments, major and minor inspections, engine changes, modifications and repair of enemy action damage.

(d) The remaining 10 per cent of the maintenance establishment was made up of workshops and stores personnel, cleaners, runners, etc.

Ground crews were not employed at all times at maximum pressure but economy in their manpower offered difficulties. Simple reduction in the number of men per ground crew was not feasible, since the ground crew was already as small as was compatible with safety. If two ground crews were pooled for the servicing of two aircraft, additional flexibility of working would be obtained (since there was often more work to be done on an aircraft than on its neighbour), and fewer men would be required in the combined gang than in the sum of the two gangs working separately. This pooling scheme had been tried with success.

The question of reducing the number of ground crews per squadron was also considered. Each aircraft required for operations or training at night must undergo during the preceding 24 hours a daily inspection and possibly minor repairs also. There was not time for one crew to carry out two such inspections in one day, and to share an extra inspection among more than one crew would be an undesirable division of responsibility. Hence a reduction in ground crews could be achieved only at the expense of reducing the maximum possible effort. Examination of the frequency distribution of the number of sorties despatched per squadron over a period of one year suggested that a reduction of 19 per cent in the number of ground crews per squadron would lead to a reduction of only 4·9 per cent in the number of sorties per squadron. On the other hand, ground crews would take less interest in the care and maintenance of aircraft if they were not able always to work on the same one. Also, the call for station duties, night maintenance parties, etc., would have to be met by a reduced number of men.

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Taking the last point into consideration, an increase of 15 per cent in the flying output per ground crew could probably be achieved in this way. The manpower saved might be diverted to form new squadrons or, a more economical procedure, existing squadrons might be enlarged in respect of aircraft and aircrew, but not in respect of ground crews.

The specialist workers were employed to capacity and offered no possibility of economy in manpower, indeed, armourers (bomb) had to be supplemented by other personnel when a specially heavy effort was in preparation.

The number of aircraft under repair by each H.Q. Maintenance Flight each day was given within fairly close limits on Form 'Q', the serviceability state signal. It was thus possible to construct frequency distributions showing the number of days in a given period on which one, two, three, etc., aircraft were in process of repair at selected operational units. A reasonable estimate of the capacity of an H.Q. Maintenance Flight was five aircraft per day. On this basis an analysis was made in which one aircraft-day below capacity was counted for a day on which four aircraft were shown as receiving attention; and so on up to five aircraft-days below capacity whenever no aircraft were shown as receiving attention. The total number of aircraft-days below the capacity of the maintenance staff could then be compared with the actual performance of the maintenance staff in aircraft-days. It was concluded that, with a uniform flow of work, 100 per cent of the existing maintenance strength could cope with 150 per cent of the existing tasks. ~~Alternatively, 67 per cent of the strength could cope with 100 per cent of the existing tasks.~~ Alternatively, 67 per cent of the strength could cope with 100 per cent of the existing tasks, offering a release of 33 per cent of the manpower engaged in H.Q. Maintenance Flights. As the jobs to be undertaken could not be made to arise at regular intervals, investigation of methods of alleviating the effects of irregularity were of the greatest importance.

The possibility of establishing group maintenance organisations to undertake the lengthier repairs and inspections was considered as a means of smoothing out some of the irregularities in the flow of work. By operating with pools of unserviceable and serviceable aircraft, these organisations would ensure full-time employment for their staffs and at the same time be in a position to effect an immediate supply of serviceable aircraft to squadrons in exchange for those which

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were unserviceable. This scheme was not regarded as workable, mainly on account of the difficulty of flying the unserviceable aircraft back to the Group depot for repair. Group Initial Fitment Depots to carry out acceptance checks and the fitting of initial modifications on new aircraft would, however, be a practical proposition and their formation was recommended. The existence of Group Servicing Parties, which consisted of approximately 90 tradesmen used to supplement the maintenance flights of squadrons which had experienced an abnormally high incidence of unserviceability, was commended as a material aid to avoiding a waste of manhours.

The pooling of the manpower in the maintenance flights of the squadrons making up a base or station was also a development which, by smoothing out many of the fluctuations in the arisings of work, would lead to manpower economy. The disposition of the personnel would be in the hands of the Base or Station Engineer Officer who would balance the needs of the squadrons concerned according to their ability to meet operational requirements. The ground crews and most of the specialists would be unaffected by the change. The men of the maintenance flight would be mobile but would remain quartered on their present station, the appropriate, variable number being transported daily from the less busily engaged squadron or squadrons to the others. In step with this arrangement, as many as possible of the subsidiary sections which carried out repairs and testing of parts and accessories away from the aircraft, should be centralised. It was estimated that these measures would make possible the release of approximately 15 per cent of the maintenance flight personnel, that is, 5 per cent of all maintenance personnel, to form a nucleus of skilled labour for new squadrons.

In addition to recommending the centralisation of subsidiary sections on a station basis and the formation of Group Initial Fitment Depots, the paper suggested that squadrons might successfully be enlarged by the addition of 20 per cent more aircraft, 20 per cent more aircrews and 20 per cent more specialist maintenance personnel.(1) This could be expected to lead to a 20 per cent increase in flying, which the existing maintenance personnel, if pooled, and the existing ground crews should have been able to support. It was recommended that

(1) 'A Study of Maintenance Manpower in Operational Squadrons of Bomber Command'. Bomber Command O.R.S. [redacted] Memo. No. 36 dated 4 June 1943. (A.H.B.2 unindexed).

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an experiment on these lines should be conducted at one Base to test the validity of these estimates but permission to carry out this experiment was refused by Air Staff, Bomber Command, on account of the danger of interfering with operational effort.

In parallel with the Bomber Command O.R.S. investigation, the Engineer Branch had been ~~examining~~ its tasks afresh and had evolved the Base organisation which, it was considered, would largely cover the Bomber Command O.R.S. recommendations. A 'clutch' organisation was to be adopted, with two squadrons to a station and three stations to a base. Major repairs, major inspections, acceptance checks and initial modifications would be performed by the Major Servicing Unit at the Base, where the subsidiary sections would also be centralised. The institution of this system would effect a pooling of manpower which could be expected to go far to level out the effect of fluctuations in the rate of arising of unserviceability.

The next organisational problem tackled by Bomber Command O.R.S. was undertaken at the request of the Admin. Plans Section at Bomber Command. No. 4 Group had found that a higher return of sorties per flight was being obtained from its 2-flight than from its 3-flight squadrons and the Group was accordingly anxious to reorganise some of its 3-flight squadrons into 2-flight squadrons. Before taking any action in the matter, Admin. Plans asked Bomber Command O.R.S. to investigate the relative merits of these two types of squadron.

The Bomber Command O.R.S. investigation which extended over No. 1 Group Squadrons as well as No. 4 Group Squadrons, confirmed the No. 4 Group claim that more sorties per flight were being obtained from 2-flight than from 3-flight squadrons but pointed out that the 2-flight squadrons had more aircraft on charge per flight, more aircrew per flight and more ground personnel per flight.(1) Much, if not all, of the apparent superiority of 2-flight squadrons could be attributed to their more generous supply of these resources but it was possible that the 2-flight squadrons had a slight residual advantage on account of its compactness and the close control which that compactness made possible. It was possible, for example, that detailed briefing and advanced training could be more effectively handled in a 2-flight squadron. In order to amass evidence

(1) 'Two-Flight versus Three-Flight Squadrons'. Bomber Command O.R.S. Report No. B.208 dated 10 May 1944. (A.H.B./IIH/241/22/12a).

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on this point it was recommended that two of the 3-flight squadrons in No. 4 Group should be formed into three 2-flight squadrons, with the proviso that the manning and crewing of the units should be proportioned to those of the 3-flight units, and that the progress of the two sizes of squadrons should be followed.

The research into the organisation of aircraft servicing, described in this chapter, was of fundamental, though largely indirect importance. Directly, it lent valuable support to the case for the Base system and put into true perspective the relative merits of 2-flight and 3-flight squadrons. Indirectly, it shed light on otherwise obscure but nevertheless important relationships between diverse aspects of Bomber Command organisation. As a result valuable advice on specific points could be given by reference to general principles and the implicit consequences of particular policy decisions were more readily able to be appreciated. Later research also owed much to the present work, for an appreciation of the relationship between flying and maintenance support was essential to the work on the aircrew/aircraft ratio and on the scheme for the so-called statistical control of resources. So long as there is an operational task of the Bomber Command type to plan for, this basic work is likely to remain of substantial importance.

The Aircrew/Aircraft Ratio

In the course of considering early in 1943 whether Bomber Command operational squadrons should be established with 20 aircraft, of which four were held in reserve, instead of 18 aircraft, of which two were held in reserve, it was found necessary to review the question of aircrew establishments. The correct establishments of aircraft, of aircrew and of maintenance personnel and the flying capacity of a unit or force are all bound up very closely with one another as earlier work on the organisation of servicing support for the flying effort had revealed. The nature of the relationship in respect of the balance between aircrew and aircraft was not, however, very clear and Bomber Command O.R.S. undertook an investigation into the matter.

The O.R.S. investigation served three purposes. It threw light on the nature of the connection between the numbers of aircraft, aircrews and maintenance men in operational units and the sorties performed by the units; it provided a method of checking the correctness of the balance between these factors in any

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unit or group by examination of records; and it discussed the need for modification of the currently adopted aircrew/aircraft ratio of 1·1.(1)

The basic principle was formulated that the aircrew/aircraft ratio, i.e. the proportion of aircrew on strength to aircraft on strength, should be such that there was one fit crew to man each serviceable aircraft when the opportunity for large-scale effort arose. This would necessitate an ideal solution in which the ratio went up with an increase in serviceability or with a decrease in crew effectiveness. Such variation of the ratio was not practicable, so that the best compromise was to adjust the ratio to accord with the mean values of the serviceability and crew effectiveness. It can easily be seen that the required aircrew/aircraft ratio was equal to the ratio of percentage aircraft serviceability to percentage aircrew effectiveness. Though the aircrew/aircraft ratio for a given aircraft type in a group as a whole might be correct, the number of serviceable aircraft with crews might still fall short of the actual number of serviceable aircraft because of deviations from the correct aircrew/aircraft ratio in individual squadrons. Since crews and aircraft of squadrons were not interchangeable, a correction factor had to be introduced to ensure that all the serviceable aircraft in the Group were provided with crews. The correction factor for this purpose was obtained by observing the magnitude of the difference between the number of serviceable aircraft and the number of serviceable aircraft with crews in the Group as a whole from past records.

Further, an assumption was necessary as to the operational intensity of which aircrew were capable. With reference to past experience it was assumed that an aircrew could operate on two successive nights but not on three. Moreover, it was considered that the weather offered so small a number of opportunities of flying on any third consecutive night that it was not worthwhile providing the additional crew capital required to seize such opportunities.

On examining from Bomber Command Form G the mean aircrew fitness and the mean aircraft serviceability over a four-months period, it was found that the current aircrew/aircraft ratio was correct for the Operational Bomber Force as a whole under the prevailing conditions. Deviations from the standard ratio were

(1) 'Investigations into the Aircrew/Aircraft Ratio in Operational Squadrons of Bomber Command'. Bomber Command O.R.S. Report No. 85 dated 7 November 1943. (A.H.B./II/39/1).

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found necessary in the case of certain types in certain groups. It was also found that the ratio deviated from the correct value in the case of certain types in certain groups; different forms of remedial action and their probable effects were discussed.

In order to maintain the required balance it was suggested that a graphical record should be kept at Command H.Q. to show the number of fit aircrews plotted against the number of serviceable aircraft of each type for each group, taking mean values over a week and adjusting the graph weekly, and that a similar graph by squadrons be maintained at each group.

Perhaps the most important aspect of O.R.S. Report No. 85 was the graphical technique used to present and discuss the statistics obtained; the method employed served to illustrate the nature of the connection between the numbers of aircraft, aircrews and maintenance men. A representative point corresponding to a certain aircraft type in a specified group was plotted against rectangular co-ordinates, of which the ordinate was the prevailing aircrew/aircraft ratio and the abscissa was the required aircrew/aircraft ratio appropriate to the aircraft serviceability and the aircrew fitness. The points were considered in relation to the diagonal straight line, the so-called 'parity line', on which the actual and required aircrew/aircraft ratios were equal, and in relation to the family of curves of constant flying capacity. The curves of constant flying capacity were actually lines of constant total of aircraft with crews available in a given period. For large values of the ordinate such a curve was parallel to the ordinate axis; it curved round in the neighbourhood of the parity line to become, for large values of the abscissa, parallel to the abscissa axis; the equation to this family of curves was developed in Bomber Command Internal Memorandum No. 37 dated 19 October 1943.[1] For points on the parity line, aircrew, maintenance personnel and aircraft were balanced; as a point moved up the parity line the flying capacity increased.

A point, not on the parity line, might be moved on to the parity line by altering any one of the three factors, aircraft on strength, aircrews on strength and strength of maintenance personnel. If the point was below the line, the economical course of action was to increase the actual aircrew/aircraft ratio

(1) 'Equations of the Constant Flying Capacity Curves'. (A.H.B.2 unindexed).

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by increasing the number of aircrews or decreasing the number of aircraft, or to decrease the serviceability, and hence the aircrew/aircraft ratio required to utilise the serviceability, by a decrease in the number of maintenance men. Conversely, if the point was above the line, action might be taken to decrease the actual aircrew/aircraft ratio by decreasing the number of aircrews or increasing the number of aircraft, or to increase the serviceability by an increase in the number of maintenance men. It will be noted that a change in the strength of aircraft or aircrew would affect the flying done and hence the serviceability; hence the point would not move vertically. Which of the courses should be adopted would depend on the relative scarcity of aircraft, aircrews and maintenance personnel, and on whether it was desired to do more or less flying than before, or an equal amount.

The above considerations should not be taken to imply that for a given opportunity cycle there was a linear relationship between serviceability and maintenance manpower strength but merely that the former was an increasing function of the latter. Since serviceability could only approach the limit of 100 per cent by extravagant use of manpower, there would come a stage when serviceability would increase very slowly with increasing maintenance manpower strength. This would have to be considered in deciding whether to alter the strength of maintenance personnel rather than aircrew or aircraft strength in order to achieve balance between these resources.

An account of views expressed when the O.R.S. Report No. 85 was presented to R.A.F. Staff, Bomber Command, is to be found in Bomber Command O.R.S. Internal Memorandum No. 38 dated 21 December 1943.(1) The proposal that a running check on aircrew provisioning on the lines suggested should be kept was rejected because the A.O.A.'s Branch considered that their own methods of watching the position were adequate.

In December 1943 it was proposed that the establishment of aircrews in operational squadrons should be increased from 11 to 13 or 14 per flight of 10 aircraft.(2) The results of the O.R.S. investigations into the probable effects

(1) 'The Aircrew/Aircraft Ratio'. (A.H.B.2 unindexed).

(2) 'Points for discussion at Air/Admin./Training Conference to be held in A.O.A.'s Office at 1500 hours on Monday 6 December 1943.' Bomber Command O.R.S. [illegible] Memo. No. 39 dated 5 December 1943. (A.H.B.2 unindexed).

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of this proposal are to be found in Bomber Command O.R.S. Internal Memoranda Nos. 40, 41 and 42 dated 3rd, 4th and 4th December 1943 respectively.[1] The short-term and relatively unimportant advantage secured would be an initial non-recurrent gain in sorties until the inability of aircraft replacements to keep pace with wastage brought the output back to its original level. More important, greater scope would be afforded for concentrating the effort into the most suitable weather periods. For example, three successive nights of large-scale operations instead of only two would be made possible by maintaining an aircrew/aircraft ratio of 1·4 in the Main Force and 1·2 in No. 8 (P.F.F.) Group. This would increase the striking efficiency of the Force and might tend to decrease the wastage rate. Further, reduced frequency of operations by individual crews might, by a reduction in strain and fatigue, assist both in improving the effectiveness of raids and in reducing the loss rate. The action taken was to increase aircrew/aircraft ratio to 1·4.

After the aircrew/aircraft ratio had reached and exceeded 1·4 for some weeks, it was found that the number of aircraft with crews of ten fell short of the number of serviceable aircraft. This was found to be due mainly to wide variations in the ratio from group to group and from unit to unit.[2] A surplus of crews in one unit did not compensate for a deficiency in another and, unless the ratio stood at or near 1·4 in every operational unit, there was a probability that the number of aircraft with crews in operational units taken together would sometimes fall short of the total of serviceable aircraft. Further, cases (which it would be extravagant to allow for) of abnormally high serviceability or low crew effectiveness were inevitable occasionally; this would likewise leave a few serviceable aircraft unmanned.

In 1945, it became necessary to consider whether an aircrew/aircraft ratio of 1·4 was adequate to support both day and night operations.[3] The normal effort required of a squadron was a 'Derby' effort, consisting of 70 per cent of the U.E. aircraft available with crews, provided that this did not involve

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(1) No. 40 - 'Considerations affecting the Proposed Increase of Aircrews from 11 to 13 per Flight of 8 + 2 aircraft'. (A.H.B.2 unindexed).
No. 41 - 'The Aircrew/Aircraft Ratio for Sustained Operations'. (A.H.B.2 unindexed).
No. 42 - 'Loose Minute (Aircrew/Aircraft Ratio)'. (A.H.B.2 unindexed).

(2) 'The Balance of Serviceable Aircraft and Fit Aircrews'. Bomber Command O.R.S. [redacted] Memo.No. 43 dated 17 December 1942. (A.H.B.2 unindexed).

(3) 'A Note on the Adequacy of 14 Aircrews per Flight when both Day and Night Operations are undertaken'. Bomber Command O.R.S. [redacted] Memo.No. 44 dated 14 March 1945. (A.H.B.2 unindexed).

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declaring fit any crew, which was training for a special operation or which would have operated twice during the 48 hours immediately prior to the projected operation. Occasionally 'Goodwood' efforts, when all crews not on leave or sick, were required to fly, were necessary. In general, this scheme would not require a more intense effort per crew than was required when the aircrew/aircraft ratio of 1·4 was established, although then only night operations were contemplated. Accordingly, no change in the aircrew/aircraft ratio was considered necessary.

Two other pieces of investigation into this subject deserve mention here. One was done at the time when the aircrew/aircraft ratio permitted not more than two successive nights of large-scale operations and was concerned with estimating the gain in sorties that might result from an increase in the aircrew/aircraft ratio sufficient to permit three-night flying.(1)

The other piece of work was a largely theoretical investigation into the question of sustained effort.(2) A unit with a fixed number of aircraft was considered. After a spell without flying, at the end of which the serviceability stood at 80 per cent, the unit was required to operate as heavily as possible. The rate of arising of unserviceability was to be 25 per cent of sorties despatched and the rate of restoration to serviceability during any day was to be 30 per cent of all the aircraft which were unserviceable at 1800 hours on the previous day. It was assumed further that no limitation on effort was imposed by shortage or fatigue or aircrews. It was shown that these assumptions lead to a close approximation to the states arising in practice in an actual squadron, both as regards serviceability and as regards the equilibrium state after several nights of sustained effort. It was deduced that the assumptions governing arisings and restoration rate of unserviceability provided the closest fit to actual conditions attainable with reasonably simply hypotheses.

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(1) 'Estimate of Increase in Flying Obtainable with the Increased Aircrew/Aircraft Ratio'. Bomber Command O.R.S. [redacted] Memo.No. 45 dated 17 August 1943. (A.H.B.2 unindexed).

(2) 'Theoretical Study of Sustained Effort by Aircraft'. Bomber Command O.R.S. [redacted] Memo.No. 46 dated 1 September 1943. (A.H.B.2 unindexed).

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The case in which aircrew provisioning could limit effort was similarly treated in Bomber Command O.R.S. Internal Memorandum No. 46. The assumptions of the previous case were retained except the one regarding aircrew availability. An aircrew/aircraft ratio of 1·15 was assumed with an allowance for non-effectiveness of 25 per cent. Crews could operate on two nights out of three, but not on three successive nights. Half the crews could operate on three nights out of four and all on three nights out of five but none on four nights out of five. On this basis the total sorties performed in a period of seven days' sustained effort, the distribution of the effort and the excesses or deficiencies of aircrew available relative to aircraft available were estimated.

In the work outlined in the earlier part of this chapter, a valuable basic principle was laid down and light was thrown on the relationship between flying effort and the provision of aircrew and other resources but the problems were treated in an ad hoc manner as they arose. In the work described in the preceding two paragraphs, some attempt has been made at a theoretical approach and this may well form the proper starting point for future research.

Statistical Control of Resources

In April 1944, the shortage of manpower was once more emphasised as the main factor limiting the expansion of the Air Force in a letter from the Air Council to various Commands, including Bomber Command.(1) It was necessary that the flying hours obtained should be closely related to the technical manpower used to produce them; by this means any inefficient or uneconomically manned units could be immediately detected. A memorandum by the Air Staff, describing the principles underlying the relationship of maintenance organisation to flying effort, accompanied the letter. Attention was drawn to the success of these principles in affording by their application large economies in manpower in both operational and training units and it was suggested that Operational Research Sections should investigate applications of the principles in their own Commands. Later, representatives of D.D. Science and D.D.O.(P), Air Ministry, visited Bomber Command to discuss the problem. In consequence Bomber Command O.R.S. undertook an investigation of flying output in relation to maintenance resources in the operational units of Bomber Command.

(1) A.M. File C.S.22402/S.6. Letter dated 17 April 1944.

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At the time of the investigation Bomber Command operational units were distributed among Nos. 1, 3, 4, 5, 6, 8 and 100 Groups. It was decided not to investigate No. 100 Group, which was concerned with radar countermeasures, in view of the peculiarity of its task. The other groups were mostly organised into bases, each of which controlled two or three or four stations. The stations in No. 8 Group and some stations in Nos. 3 and 4 Groups were outside the Base system; most of them were self-accounting directly to the corresponding group while others were of sub-station or satellite status and under the control of a parent station. Each station housed one or two squadrons, each holding twenty or thirty aircraft; normally a squadron in sole possession of a station held thirty aircraft and each squadron, sharing a station with another, held twenty aircraft.

Bomber aircraft, operational at this time, were Lancaster I, II and III, Halifax II, III, V and VII, Stirling I and III and Mosquito IV, IX, XVI and XX. Halifax II and V, Stirlings and Lancaster II were going out of operational service. A few Hudson III and IIIA, Stirling IV and Lysanders were also in operational service for special duties in No. 3 Group.

The maintenance personnel on each station were organised into a Repair and Inspections Squadron (R. & I. Squadron) and a Daily Servicing Section (D.S.S.). The D.S.S. carried out daily inspections and remedied petty unserviceability while the R. & I. Squadron carried out minor inspections and performed major repairs. Each base had a Base Major Servicing Section (B.M.S.S.) which carried out major inspections on all aircraft in the base and initial checks on aircraft as they arrived in the base.(1) The R. & I. Squadrons of stations in Nos. 3 and 4 Groups of parent or independent status did the major inspections on their own aircraft and on those of their satellites or sub-stations, if any. All the major inspection work on aircraft in No. 8 Group was done in two Group Type Major Servicing Sections, one for Lancasters and one for Mosquitos.

The first step in the investigation was to collect information about the flying hours and sorties performed by various units and about their strength in aircraft, aircrew and maintenance personnel. Operational and non-operational

(1) Minor and Major Inspections were done periodically on a basis of flying hours. Minor Inspections were done after 50, 100, 150, 200, 250, 300 and 350 flying hours and Major Inspections after 400 flying hours; the cycle then repeated itself.

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flying hours were available by squadron weekly on a flying hour return made to the Engineer Branch at Headquarters; other sources were available but considered less reliable. Sorties were obtained by squadron monthly from the monthly news of the various groups. The aircraft holding of each squadron day by day was obtained from Form Q and the aircrew strength of each squadron day by day on Form G. The maintenance personnel strength of each station and of each major servicing section was given for the end of each month on Form 1753. This information for each base or station of independent status (including any sub-stations or satellites) in Nos. 1, 3, 4, 5, 6 and 8 Groups for May and June 1944, is tabulated in Bomber Command O.R.S. Report No. S.214 dated 16 February 1945.(1) The existence of Base Major Servicing Sections made it difficult to take as unit the station rather than the base as a whole; for rough comparison of flying output in relation to manpower backing between stations within a base the manpower backing of the B.M.S.S. might be divided among the stations of the base in proportion to the flying hours performed by each in the period under review and such a procedure had to be adopted in the case of No. 8 Group.

It was thought that it would also be necessary to take account for each unit of the amount of flying each of its aircraft could do before its next periodical inspection. If q was the number of hours an aircraft was due to fly before its next major inspection, the set of values of q for all the aircraft in a unit formed the Major Stagger Chart for the unit. The Minor Stagger Chart could be drawn in the same way by plotting the flying hours to the next minor inspection. It might be that one unit performed more inspection work than another in a given period and therefore in comparing their flying outputs in relation to maintenance manpower over the period it was necessary to examine the change in the stagger state of the two units. Further one unit might be in a better position to take advantage of operational opportunity than another with a less suitable stagger state.

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(1) 'A Method of Approach to the Problem of Manpower Utilisation in the Operational Units of Bomber Command'. (A.H.B./II/39/1/1).

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Stagger charts were not convenient for analytical purposes and might be replaced by the Minor and Major Inspection Potentials, P_1 and P_2 respectively. Definitions and a full account of the properties of these functions are to be found in a paper by D.D. Science III/2 dated 12 August 1944.[1] They were defined first for individual aircraft; the Major and Minor Potentials of a unit were the respective sums of the Major and Minor Potentials of each of its aircraft. The Total Potential of a unit was defined as the sum of the Major and Minor Potentials of the unit. The higher the Total Potential of a unit the more flying it could do for the expenditure of a given number of manhours. Calculation of Potential required knowledge of the average manhours expended on the Major and various Minor Inspections and the position of aircraft in the Flying Hours Cycle of Inspections. The former was known sufficiently well by the Command Engineer Branch but the latter could be found only by examining the Forms 700 for each aircraft on every unit under consideration.

Since the collection of necessary data was such an extensive undertaking, it was decided to make a preliminary quantitative examination of the effect of Potential in a few units with a view to discovering whether failure to take account of it would lead to serious error. The existence of many other complicating factors necessitated care in the choice of units for investigation, which fell on Nos. 13 and 14 Bases.[2] Accordingly a representative of O.R.S. visited No. 1 Group to make a detailed examination of the working of Nos. 13 and 14 Bases and to collect the necessary information from the Forms 700. At the same time the whole problem in hand formed the subject of discussions between O.R.S. and the Command Engineer Branch with the A.O.C., the Base Commanders and various Engineer Officers at Group, Base and Station level in No. 1 Group.[3]

With the background of these discussions and in the light of the data examined for a great many units, it was possible in O.R.S. Report No. S.214[4] to lay down principles and sketch a procedure for rationalising the manpower situation in the operational units of Bomber Command.

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(1) 'Planning and Control Indices in the R.A.F.'

(2) 'The Flying Hours per Man Efficiency Index in Nos. 13 and 14 Bases'. Bomber Command O.R.S. [redacted] Memo.No. 47 dated 14 September 1944. (A.H.B.2 unindexed).

(3) 'Report on visit to No. 1 Group to discuss Flying Hours per Man'. Bomber Command [redacted] Memo.No. 48. (A.H.B.2 unindexed).

(4) A.H.B./II/39/1/1.

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Provided the average capabilities of the personnel on different stations were the same (and over an aggregate of sections this might be expected generally to be true), a necessary but not sufficient condition for the maximum utilisation of manpower was that the work done per man on each unit should be the same. If one unit achieved more work per man than others, then it was clear that maximum effort was not being obtained all round and manpower was being wasted.

The work which a unit had to perform on each of its aircraft might be divided into work which had to be done whether the aircraft flew or not, work such as bombing up and seeing aircraft off which depended on the number of sorties performed and the work at periodical inspections which depended on the number of flying hours performed. The load on the maintenance personnel due to these three factors was represented by the indices 'Aircraft on Charge per (Servicing) Man', 'Sorties per (Servicing) Man' and 'Flying hours per (Servicing) Man'. The load due to the first factor was comparatively small. Since the number of sorties performed was usually a fair indication of hours flown and vice versa, the load might be represented almost equally well by either of the last two factors. Accordingly either 'Sorties per Man' or 'Flying Hours per Man' might be taken as the primary index of the utilisation of maintenance manpower and recourse had to the other two indices as a matter of routine.

Accordingly, if the 'Flying Hours per Man' of a unit was lower than the maximum it was reasonable to suspect wastage of manpower and an investigation into the cause was worth while. Explanations of differences might be used as a guide on how to bring the effort in relation to manpower of all units up to that of the best.

It might be observed of a unit with a low 'Flying Hours per Man' that it was required to participate in fewer operations than other units. This might be because it was equipped with an aircraft type which was unsuitable for certain kinds of operations. If this were the reason for the low 'Flying Hours per Man', then a reduction in manpower was indicated. If there was no such explanation for the lowered operational opportunity of a unit, then it might be brought to the attention of the Group that the flying programme of the unit would be increased and to the attention of the Command that a corresponding increase in

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the effort of the Group might be expected. This would be of real importance when a peak effort was required of the Command.

A poor performance on the part of a unit might be due to the fact that the unit had not sufficient aircraft to take advantage of operational opportunity when it arose. An increase in the number of aircraft on strength or a decrease in personnel was then indicated. If the trouble was due to an insufficient number of aircrew to fly the aircraft then increased efficiency would be obtained by increase in aircrew or decrease in aircraft and ground personnel. Airfield capacity (of runways or working or domestic accommodation) might be the deciding factor as to which of these courses was adopted.

Again, a poor performance might be due to the layout and conditions of the airfield (and, in the case of a Base, the disposition of resources within the Base). If nothing could be done to improve the conditions of such airfields, it might be worth while to consider which units to locate there. The choice should fall on units from which little flying was required; least manpower would then be affected by these conditions and therefore least wastage of manpower would result from them.

If no explanation of a low output in relation to manpower in a unit was forthcoming, then some defect in the organisation or inefficiency in the unit was to be suspected. The unit would then form a suitable object of investigation for an Air Ministry Manpower Research Unit or similar organisation.

In some of the circumstances described in the preceding paragraphs a reduction in the manpower of a unit was recommended as the appropriate measure. If the circumstance, for example, lack of operational opportunity, was temporary, likely to last, say, less than four months, then a removal of men would be inadvisable. Instead of that, the unit might be required to take over some of the periodical inspection work of more hard-pressed units.

It was proposed that the Command Statistical Section should collect the following statistics for each unit monthly:-

(a) Operational and non-operational flying hours.
(b) Operational and non-operational sorties.
(c) Mean Aircraft strength.
(d) Average of the ratio Fit Aircrew/Serviceable aircraft.
(e) Servicing manpower strength.
(f) Numbers of Major and Minor Inspections and Acceptance Checks performed.
(g) Numbers of Aircraft missing or Cat. E.
(h) State of Inspection stagger.

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A suitable new or already existing Command Section should be made responsible for the interpretation of the statistics and for the determination of any changes required in the disposition of manpower and other resources. This section would advise such changes to the appropriate Headquarters Branch for the necessary executive action.

The O.R.S. and the R.A.F. Staff, Bomber Command, were by no means in full agreement in this matter. The exchange of views, consequent upon the submission of Bomber Command O.R.S. Internal Memorandum No. 32 dated 25 November 1942 (1) in draft form to the Air Officer i/c Administration is documented in Bomber Command O.R.S. Internal Memorandum No. 49 dated 8 January 1945. (2) The R.A.F. Staff considered that the imponderable factors would assume major proportions and that in the interval, during which the analysis of performance took place, the changes, if any, that could be recommended would be out of date. The O.R.S. proposals and the R.A.F. Staff comments were published side by side in Bomber Command O.R.S. Report No. S.214 dated 16 February 1945. (3)

It was agreed that a preliminary trial of the scheme should be carried out. Statistics (f) and (h) of the above paragraph were to be obtained from units only in the particular cases where a knowledge of them appeared essential to a full appreciation of the situation. The Command Statistical Section were to provide the statistics and Admin. Plans and O.R.S. were to combine in interpreting them. The trial had not got under way by the end of the war in Europe and thereafter the scheme was abandoned.

Statistical Study of Aircraft Inspections

Besides research into the problems of how best to meet the programme of work necessary to support a given flying effort, work was also undertaken with the aim of reducing the actual volume of work associated with a given amount of flying. Such was the aim of the Bomber Command O.R.S. work on aircraft inspections. Aircraft received a routine daily inspection and, in addition, a more thorough periodical inspection every so many flying hours. Most periodical inspections were of the type known as minor inspections but every eighth periodical inspection was of the more complete type called major inspections. Bomber Command O.R.S. work on aircraft inspections was mainly concerned with the study of periodical inspections.

(1) A.H.B.2 unindexed.

(2) 'Manpower Utilisation in the Operational Units of Bomber Command.' (A.H.B.2 unindexed).

(3) A.H.B./II/39/1/1.

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In September 1943, a report on inspections was received from Coastal Command O.R.S. who had arrived at the conclusion that more time was being spent on inspections than was justified by the decrease in repairs and failures which the inspections brought about.(1) Their report suggested that the expenditure of less time on inspections and a little more on repairs would yield a dividend in flying hours per maintenance man. Bomber Command O.R.S. forwarded this report to the Engineer Branch with the suggestion that it might be valuable to investigate in Bomber Command the distribution of repairs arising on the most important aircraft types, say the Lancaster I and III and the Halifax III, then working to a Minor Inspection Cycle of 50 hours, with a view to determining whether an extension of the periodicity would be safe and practicable.(2) The ensuing exchange of views is documented in Bomber Command O.R.S. Internal Memoranda Nos. 51 and 52 dated 1 and 17 October 1943 respectively.(3) The Engineer Branch was not convinced of Coastal Command O.R.S.'s theory of minor inspections but asked O.R.S. to undertake further investigation.

Briefly the problem undertaken was to determine the probable effect of extending the periodicity of minor inspections of Lancasters in operational units beyond fifty flying hours. These inspections absorbed a large number of maintenance manhours and the lengthening of the minor period would consequently be a considerable saving. If the increase could be effected without a disproportionate increase in the number of repairs arising and especially in the number of operational failures, the manpower saved could be diverted to increase serviceability and operational effort elsewhere.

For the purpose of the investigation the period between successive inspections was divided into classes of ten flying hours, 0 - 10, 10 - 20 etc., and the number of repairs arising from flights in these classes was ascertained from Forms 700. All the Forms 700 available from the Lancaster squadrons of Nos. 1, 5 and 8 Groups were examined and over 5,000 entries were used in compiling the necessary data. Certain precautions were necessary to exclude the effect of extraneous factors; in particular, rectifications performed after air test had to

(1) 'Inspections'. Coastal Command O.R.S. Report No. 241 dated 21 July 1943.

(2) 'Notes on Coastal Command Paper on Inspections (C.C./O.R.S. Report No. 24)'. Bomber Command Int. Mem. No. 50 dated 19 September 1943. (A.H.B.2 unindexed).

(3) No. 51 - 'Bomber Command File S.30634/O.R.S., Mins. 3 and 4'. (A.H.B.2 unindexed).
No. 52 - 'Aircraft Inspections' (A.H.B. unindexed).

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be separated from repairs arising from flying performed between inspections as the former properly belong to the inspections themselves.

It was found that the repair rate (that is, the number of repairs per flying hour) remained substantially constant throughout the minor inspection cycle. There was some evidence that the repair rate declined through the cycle but this was not very strong. At any rate it was clear that an increase in the periodicity of minor inspections would not lead to a disproportionate increase in repairs in the later stages. Furthermore, the number of operational non-enemy action failures was highest in the ten hours following a minor inspection and then decreased until the next minor.

A full account of the methods used in and results obtained from this investigation is to be found in Bomber Command O.R.S. Report No. 97 dated 17 January 1944,[(1)] which recommended an experimental extension of inspection periodicity to 75 hours in a few selected Lancaster squadrons, in which repair and failure rates would be carefully checked by a Time-Recording Party. The Engineer Branch was in full agreement with the report and the proposed experiment was put into effect in two Lancaster squadrons at Waddington in No. 5 Group.

A Time Recording Party recorded the manhours on repairs between inspections and the manhours spent on minor inspections on the Lancasters, working to a 75 hour cycle. It was found that the number of manhours expended on repair towards the end of the 75 hour period was on the average rather less than the number expended towards the beginning; this phenomenon was believed to be due to the disturbance caused by a minor inspection. Further, the number of manhours spent on a minor inspection and on the rectifications arising from it was no greater when the inspection was performed at 75 hours than when it was performed at 50 hours. A report on this investigation is to be found in Bomber Command O.R.S. Report No. 105 dated 10 August 1944,[(2)] which recommended that the minor inspection period of all operational Lancaster aircraft should be extended from 50 to 75 flying hours, with a proportionate extension of the major inspection period and that a similar experiment should be undertaken with operational Halifax aircraft.

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(1) 'The Incidence of Repairs and Failures related to the Number of Hours flown by an Aircraft since its last Periodical Inspection'. (A.H.B./IIM/a1/4a App.).

(2) 'The Experimental Extension of the Minor Inspection Period for Operational Lancasters from 50 to 75 Flying Hours'. (A.H.B./IIM/a1/4a App.).

The Engineer Branch was satisfied that the proposed extension of inspection periodicity was justified for all operational Halifax and Lancaster aircraft (1) and this measure was put into operation without experimental work on Halifaxes. This meant a manpower saving of some 10 per cent of Repair and Inspection squadrons on operational units. If the measure had not been possible, the Command Engineer Officer considered that an increase of maintenance personnel would have been necessary to meet the increased flying programme which Bomber Command was then fulfilling.

A similar investigation was carried out for Wellingtons. The manhours on repair between minor inspections were recorded by an A.M.M.R.U. at No. 26 O.T.U. and were related to flying hours. The relationship between crash rate and flying hours since the last minor inspection was investigated by examining Forms 700 from all Wellington O.T.U.s. No firm conclusions with regard to the optimum periodicity of minor inspections were drawn from the investigation but the interesting result that the crash rate was independent of hours flown since the last inspection, at least as far as 40 hours, suggested itself. For further information, reference should be made to Bomber Command O.R.S. Internal Memorandum No. 54 dated 11 September 1945. (2)

A further question which arose with regard to inspections was whether flying hours was the most suitable basis for their periodicity. It was pointed out that parts of an aircraft which deteriorate solely by weathering should be inspected at intervals of a fixed number of days, while others which deteriorate mainly as a result of the stresses imposed on take-off or landing should ideally be inspected on a basis of number of flights. (3) Parts which deteriorated in proportion to the flying hours performed should continue to be inspected on a basis of flying hours. It was felt in Bomber Command that such a compound system of inspections would unduly complicate the work of the servicing staff, and would not be easily understood by personnel carrying out the inspections. Consequently there would be more room for error than with the current system. Further a squadron commander would be much less certain how many aircraft could be at his disposal in the near future, and the staggering of inspections would be

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(1) 'Bomber Command File S.30634/O.R.S. Mins. 14-16'. Bomber Command O.R.S. [redacted] Memo.No. 53 dated 31 August 1944. (A.H.B.2 unindexed).

(2) 'Periodicity of the Minor Inspections on Wellington Mark III and Mark X Aircraft'. (A.H.B.2 unindexed).

(3) 'The Waste of Manpower and the Inadequacy of Inspection resulting from basing Periodic Inspections solely on Flying Hours'. Coastal Command O.R.S. Report No. 261 dated 23 November 1943.

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made very difficult. In order to weigh up the advantages and disadvantages of the two methods of basing the periodicities of inspections O.R.S. examined the variability of flying hours, calendar days and number of landings between successive minor inspections.

The method employed in and results obtained from the O.R.S. investigation are described in Bomber Command O.R.S. Report No. S.170 dated 7 August 1944.(1) Information was drawn from all the Forms 700 available in respect of No. 4 Group Halifaxes and covered upwards of 200 minor inspection periods. Pronounced variations from normal were found in the number of days elapsing and the number of landings taking place between successive minor inspections. It was, however, considered that these variations would introduce neither undue risk on account of the under-inspection of the components affected nor serious waste of manpower due to over-inspection. The disadvantages of complication inherent in the compound basis were held to outweigh its advantages and the retention of the flying hour basis of inspection periodicity was recommended. The Engineer Branch, whose views are to be found in Bomber Command O.R.S. Internal Memorandum No. 55 dated 4 August 1944 (2) was in full agreement with O.R.S.

The Work of Recording Parties

As the work described hitherto on securing greater efficiency and a higher level of manpower economy in Bomber Command progressed the need for information on which to base decisions for action became increasingly important. Measures which could be produced by pure thinking had been explored. The coming invasion involved transfer of men from the R.A.F., and it was more than ever urgently necessary to consider further measures to safeguard the operational efficiency of the Command. An examination of maintenance manpower questions (3) in Bomber Command resulted in the conclusion that a great many technical tradesmen were being employed on station duties or work outside their own trade which should normally have been the responsibility of non-technical personnel. A possible explanation was that the domestic and administrative trades were seriously undermanned. Further conclusions reached were that work should be undertaken to

(1) 'Frequency of Periodic Inspections. The Relation between Flying Hours, Number of Landings and Lapse of Time'. (A.H.B./IIH/241/22/14).

(2) 'Bomber Command File S.30634/O.R.S., Min. 11. (A.H.B.2 unindexed).

(3) 'A Study of Maintenance Manpower in Operational Squadrons of Bomber Command'. Bomber Command O.R.S. [redacted] Memo.No. 36 dated 4 June 1943. (A.H.B.2 unindexed).

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eliminate aircraft which were uneconomical to maintain and further to improve the more suitable types.

Means were therefore considered of releasing more technical manpower and relieving the load on servicing wings and echelons, caused by a given amount of flying. The conclusions reached in Bomber Command O.R.S. Internal Memorandum No. 36, and particularly those referring to station duties, formed a basis for investigation. It was hoped by the elimination of unnecessary duties to relieve skilled servicing personnel of the chief obstruction to an increase in their productivity, and to study in greater detail the use made of aircraft time. Ignorance of the scale and frequency of extraneous duties was a serious gap in knowledge at Command and Air Ministry level; so also was ignorance of the details of the mean manpower expenditure required to complete various types of work. Such information was of importance to the establishment branches at Air Ministry in deciding on future manning of sections. It was therefore decided to investigate all these problems in relation to both technical and domestic sides of station life, for it was realised that each had important repercussions on the working of the other.

Unfortunately, existing records and returns were quite inadequate for purposes of reference. Form Q, for example, failed to account for many of the activities of aircraft (and consequently of groups of tradesmen) lasting for less than a whole day, and many serious causes of delay and waste of manpower were not evident. This inadequacy of records, together with the obvious undesirability and perhaps impossibility of attempting to obtain useful information in sufficient quantities from units themselves, made the use of Recording Parties essential.

The difficulties to be overcome were similar in all the Home Commands. Accordingly, recording units were formed under Air Ministry direction to work within the Commands. The units were to be under the immediate supervision and scientific control of the Command Operational Research Sections, but co-ordination of their activities and major decisions concerning their use were the responsibility of the Time Recording Parties Panel. This committee, consisting of representatives from Command O.R.S.'s, Time Recording Parties and Air Ministry departments, met once monthly under the chairmanship of D.D. Science.

/ Agenda

Agenda were supplied by the O.R.S.'s and the Parties, and reports were to be sent to D.D. Science for distribution to departments concerned. The Panel served as a useful link between the Scientists and the Service Departments, and also promoted the interchange of ideas and methods between the various O.R.S.'s and Recording Parties. The Parties investigating aircraft servicing and technical manpower consisted of N.C.O. technical tradesmen, and those concerned with administrative and domestic questions consisted chiefly of clerical airmen and airwomen. The administrative parties were given the name 'D.A.D.O.' Parties (Domestic, Administration, Defence and Organisation).

Logically the first step in use of the Time Recording Parties should have been the establishment of the Panel. Actually this was not so, and for the first few months the parties were used entirely at the discretion of the Command O.R.S.'s. They were eventually to investigate the problems foreshadowed in para. 2 and the first terms of reference for the party for Bomber Command were drawn up.[1]

The first work undertaken by the Recording Party in Bomber Command was largely exploratory though it had a definite purpose which it accomplished with complete success. The Party investigated the manhours spent on repairs to operational Lancaster aircraft at various stages of the flying period between minor inspections, with the intention, if possible, of revising the Inspection Periodicity. This work is discussed fully in the previous section on Statistical Study of Aircraft Inspections. The nature of the work demanded a full record of the activities of all personnel in the R. & I. Squadron and Daily Servicing Section of the station. This record, which classified the activities of the various trades under the headings, Productive Work in Trade Capacity, Other Active Duties (actually diversions), Stand-by, and Part-Day Absence, gave a good impression of the utilisation of technical manpower, and indicated where (if anywhere) manpower was either not being fully used or was in short supply:-

During this investigation the stages in the collection of information were as follows:-

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(1) A.M. File S.97292/S.M.1(a). Letter dated 22 December 1943.

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(a) Interrogation of individual tradesmen by recorders concerning their activities. Each recorder covered the activities of upwards of twenty tradesmen, and was expected to visit each at half-hourly or hourly intervals.

(b) Booking down against the name of each tradesmen his activities and their durations. For this purpose a task code was designed to represent to the necessary degree of detail every occupation likely to be met with.

(c) Summation of the time spent on various activities by each trade as a whole for each day. This was done at Command Headquarters by statistical clerks.

(d) Similar summation over the full period of recording, grouping under various headings and division by the number of days for which the recording lasted. The effect of this was to give an impression of the activities making up an average working day for any type of tradesmen.

After the investigation the methods both of recording and analysis were reviewed in consultation with S(O. & M.). It was hoped to introduce a certain degree of mechanisation into the analysis, and to make individual recorders responsible for preparing their own information for the sorting machine. In the discussions with S(O. & M.), the suggestions for mechanisation were not adopted, and it was decided that existing methods were the best that could be devised in the circumstances.[1]

Consideration was given during the last experiment to the technique to be adopted at the next station (No. 26 O.T.U.), and the following conclusions were reached. By virtue of its size (the Recording Party consisted of 24 technical and 12 D.A.D.O. recorders) an A.M.M.R.U. could record, though not in great detail, the daily activities of all technical and administrative personnel of a unit simultaneously, and from the recorded information a good general impression of the state of employment of the unit could be obtained. Alternatively by concentrating recorders in single sections in turn a much more detailed impression could be gained, and much closer study could be given to anomalies which would otherwise escape attention. Then by studying the balance of station duties between trades, the state of employment, the magnitude and causes of stand-by, and the proportion of personnel absent from the unit, an impression

(1) 'A.M.M.R.U. Methods'. Bomber Command O.R.S. [redacted] Memo.No. 56 dated 14 June 1944. (A.H.B.2 unindexed).

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could be gained firstly of whether any redistribution, elimination, or more equitable sharing of station duties could release more technical men for the task of supporting the flying programme, and secondly of whether the existing strength was adequate to the task to be performed. In addition a great deal of data useful in the estimation of establishments could be collected, including the manhour expenditure to be expected on various jobs and the number of men required to complete them in any given time.

Aircraft utilisation could also be recorded. This would take the form of half-hourly spot readings of the serviceability and repair state of all the aircraft on the unit, and could conveniently be done in conjunction with manpower recording. The use of a code would again be necessary. The incidence of petty unserviceability between inspections could be investigated in order to decide on the best periodicity for the aircraft and their role (e.g. Wellingtons used for operational training). This method could incidentally give a useful index of the relative realiability of different types of aircraft, or, (if compared with similar information from other units using the same aircraft) an idea of the quality of servicing or the effect of the operational or training role. Further developments might involve collecting overall times for various repairs and examining their frequency on a basis of flying hours, sorties, and calendar time. It was also possible in conjunction with meteorological data to assess the use made by a unit of 'fit for flying' days.

The next experiment, at No. 26 O.T.U., included most of the work and methods mentioned in the last two paragraphs, and it was here that the D.A.D.O. Party was used for the first time. Many useful statistics collected by both parties were forwarded to Air Ministry.[1] The periodicity of minor inspections for Wellington Mark III and Mark X aircraft was investigated, but no extension could be recommended.[2] Serious and unforeseen difficulties became apparent during the investigation. It was decided as a preliminary measure to bring the unit up to full establishment. The immediate result was about four hundred postings in and out, with extensive changes in the balance of many trades. Apart from imposing an abnormally heavy burden on some of the administrative sections during

(1) '33 Manhour Surveys in the R.A.F.' D.D. Science III/12 dated 1 September 1945.

(2) Bomber Command [redacted] Memo.No. 54 dated 11 September 1945. (A.H.B.2 unindexed).

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the initial stages of the investigation and reducing the efficiency of all sections through employing personnel unfamiliar with their new surroundings, such a measure was harmful in that it might have endangered the unit's ability to complete its task. It was, however, extremely valuable as an indication of the unsuitability of the actual establishment and pointed unmistakably to the need for general revision of all establishments by connecting them realistically with the task of the unit.

A further difficulty was the ban on privilege leave which was in force at the time. This had the effect of increasing the available strength of the unit and of inflating the average weekly amount of trade work done by each man. So although the ban had no measurable effect on the normal demand for station duties it considerably impaired the usefulness of the manpower statistics collected and rendered any estimate of the degree of understaffing or overstaffing of the unit extremely unreliable. It was concluded that no comprehensive manpower survey could yield extensive dividends unless conditions such as the rate of posting and the granting of privileges were not interfered with in any way. Difficulty in checking the daily sheets submitted by recorders was also experienced because of the location of the scientific staff and statistical clerks at Command H.Q. It was impossible to obtain any essential information omitted by the recorders, and it was decided that for the next investigation the statistical clerks should travel with the Recording Party.

The Recording Party moved to No. 41 Base, Marston Moor, in September 1944, and the lessons learnt during the previous investigation were put into practice. Considerably changed methods and technique were employed, particularly by the D.A.D.O. section of the party, and a different method of presentation of the results was adopted.(1) A routine was developed for calculating an establishment from the statistics obtained. This routine varied according to the working conditions of the trade, but was similar in all cases. Since the fulfilment of the task depended on the manhours of trade work performed during the period, it will be seen that the recorded trade time must not be altered unless the task was not completed. In such a case it should be adjusted according to the proportion of the task completed. The maximum attainable ratio of trade time to section time for any trade had to be decided with reference to the performance of

(1) 'Utilisation of Manpower in the Servicing Hangars of No. 1652 H.C.U. under the New Servicing Scheme. Bomber Command O.R.S. Report No. 132 dated 25 June 1945. (A.H.B./II/39/1).

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other trades of the same group working under the same conditions, to the minimum requirement for non-trade time, to equal sharing of diversions, and to the maximum possible limitation of stand-by time. To section time had to be added time for additional duties such as guards (outside working hours), giving duty time. The ratio of duty time to available time depended on the length of the working day specified by the Air Ministry. To find the required nominal strength, the available time had to be divided by a factor depending on the leave quota, the weekly allowance of free time, and the average time spent on courses, etc.

Before attemptingany revision of existing strengths it was important to consider whether the flying task of the unit was fulfilled and also whether the inspection stagger state was such as to ensure a smooth flow of work for the servicing personnel. If these conditions were not fulfilled the benefits derived from investigations by Time Recording Parties were considerably limited, and there could be no question of recommending alterations in strength on a basis of the recorded information. The results of bad stagger were evident to a very marked extent in the recording of work done in the Base Major Servicing Section of No. 41 (renumbered No. 74) Base.(1) In this case it was impossible to make any use of statistics collected, and the only results of the investigation were certain qualitative comments and criticisms of conditions of work.

It was also necessary to consider the duration of recording of any particular trade or section. If, as in the detailed recording at No. 26 O.T.U. and to a certain extent at No. 74 Base, small sub-sections were recorded for only a week, the probability of the working load and the leave distribution not being representative of average conditions was large. The probability of an uneven distribution of absent time could be reduced by recording for a sufficiently long period(2) but abnormalities of working load could only be revealed by a qualitative report. For this reason, conferences of recorders were convened at Marston Moor at the conclusion of each phase of recording, with agenda designed to reveal any peculiarities not evident from the recorded information and also adequately to qualify this information and to supply a suitable background. It was, however, essential to sort with the greatest of care such opinions and comments as were received in order to eliminate prejudice as far as possible. An example of the

(1) 'The Base Major Servicing Section of No. 74 Base, Marston Moor'. Bomber Command O.R.S. Report No. 143 dated 11 October 1945. (A.H.B./II/39/1).

(2) 'The Connexion between Nominal Strength and Minimum Duration of Recording in a Section'. Bomber Command O.R.S. [redacted] Memo. No. 57 dated 13 September 1945. (A.H.B.2 unindexed).

/results

results of such a conference can be seen in the comments on working conditions in one of the reports issued at Marston Moor.(1)

Two interesting new methods were used at Marston Moor by the D.A.D.O. party. One was the method of deriving establishments by recording and analysing both hours of work and working pressure. The other was a method of treatment for sections performing a certain number of invariable and routine tasks. Both methods can be seen in the Marston Moor Report.(2) The pressure method, although ingenious, had certain disadvantages. The arithmetical relations between the various numbers on the pressure scale were fixed arbitrarily and were not necessarily accurate. A decision had to be made regarding the proportions of the working day worked at various pressures in a section working to saturation. The length of the working day had also to be fixed in the event of no standard having been prescribed. These were important possible sources of error, to which had to be added considerable variations between the interpretations of the pressure scale by different recorders. In spite of these disadvantages the recording of working pressure obviously gave a more reliable indication of the work of a section than did the recording of manhours alone.

The second method consisted of determining the establishment of a section on a basis of, say, the mean number of forms or documents handled by it and the average number of manhours required to complete all the work necessary on each form. The method was, of course, applicable only to a section which handled large numbers of a very limited range of documents. In a Pay Accounts section, for example, maintaining pay ledgers involved a certain amount of work which varied according to the number of personnel on strength, while further work varied according to the number of postings in and out incurred in opening and closing these ledgers. The advantage of the method was that if manhour figures for the same types of work done on different stations were reasonably constant, the establishment of a particular type of section might conceivably be estimated for any station merely by the use of a formula. In establishing such a formula it would be the task of experts to determine all the possible variable factors, and time recording would be used for finding the constants.

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(1) 'The No. 1652 H.C.U. Handling Flight'. Bomber Command O.R.S. Report No. 133, Section III, dated 18 August 1945. (A.H.B./II/39/1).

(2) 'A.M.M.R.U. Investigation at Marston Moor - D.A.D.O.' Bomber Command O.R.S. Report No. 129 dated 28 May 1945. (A.H.B./II/39/1).

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Although the Recording Party went to Marston Moor aware of the errors which had been made in earlier investigations its work was gravely hampered by unforeseen administrative and servicing developments. The introduction of a completely new system of servicing and the gradual re-equipment of the whole base with new aircraft of a different mark interfered with both the extent and the usefulness of the results concerning technical manpower. The outcome was that on the technical side much greater importance had to be attached to qualitative comment. No such handicaps were encountered by the D.A.D.O. Party. The whole investigation did, however, produce some useful results, and demonstrated that there was scope for some reduction in strength in the H.C.U. Base and that the Base System as a whole was subject to great disadvantages, the chief of which was that a Base was too small a unit to effect all of the economies for which it was designed.

The termination of the investigation at Marton Moor (March 1945) by no means exhausted the possibilities of this type of work, but no further large scale experiments were contemplated, and both use and control of the parties reverted to Air Ministry. A great deal of very useful information collected had been absorbed and used both by the O.R.S.s and by the Air Ministry. Planning data for the estimation of more rational establishments were provided, and a wealth of information on conditions at station level had been amassed which could not have been obtained in any other way. The large-scale experiments had, however, failed for a variety of reasons to provide quite such comprehensive results as were expected of them. The reasons fall into two broad classes: difficulties in the administration and use of the parties themselves and difficulties in using the information collected by them.

The formation of a Recording Party of men with ability, experience and trustworthiness took a long time, and only when a party of such men had been formed could the work be of maximum value. The effect of extensive posting was disastrous, and the importance of complete screening could not be exaggerated. Personnel of the Bomber Command Party were screened from all except oversea posting, but the only result was an increase in the rate of this posting. In this way the Party lost many of its best men at Marston Moor, and through lack of suitable replacements or in some cases through lack of any replacement at all, its efforts at comprehensive large-scale recording were frequently hamstrung.

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The mass of information collected in a large-scale recording with general terms of reference was extremely unwieldy, and the task of arranging, analysing, and adequately reporting it was of such magnitude that it could not be completed quickly enough for the result to be of maximum use. Much of the qualitative comment was, moreover, of a purely local nature; because of its peculiarity to one particular station it could not be applied extensively to any other. Many recommendations made as a result of a large-scale investigation were often extremely difficult to put into effect even if the conditions which originally gave rise to the recommendations still obtained when the report was published. Further, the great difficulty of making individual recorders see a purpose in their work and understand how it fitted into a general plan reacted unfavourably on morale and made accurate information difficult to obtain.

These difficulties are a useful guide to the form which might be taken by future Recording Parties. These parties should be small and mobile and should either travel from station to station collecting and interpreting as rapidly as possible information both of general and particular application or should work with some clearly defined aim in view. Investigations of a more specialised nature were under consideration when hostilities in Europe ceased. A routine for examining quantity and pressure of work and also organisation was developed for use with the D.A.D.O. parties,(1) while the attention of the technical parties was to be concentrated on the relative merits of various aircraft types from the point of view of ease and economy of maintenance. It was also intended to study the relative reliability of aircraft and the re-arrangement of individual items in inspection schedules.(2) It is certain that in this field and in the estimation of rational establishments for special sections in a form in which they can be of general application lie opportunities for the effective use of Recording Parties in the post-war years.

<u>Miscellaneous Investigations</u>

In addition to the full-scale and, in general, long-term investigations into problems of manpower, organisation and aircraft servicing, Bomber Command O.R.S.

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(1) 'Notes on Future Approach to Manpower Research'. Bomber Command [redacted] Memo. No. 58 dated 16 November 1944. (A.H.B.2 unindexed).

(2) 'Suggested Technique for an Investigation into the Nature and Extent of Unserviceability arising on Different Types of Aircraft'. Bomber Command O.R.S. [redacted] Memo. No. 59 dated 15 October 1944. (A.H.B.2 unindexed).

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undertook a number of smaller investigations mainly for the provision of planning data. Of these investigations, those which concerned the following subjects deserve mention and are described here:

(a) Manpower Requirements for 'Window' Launcher.
(b) Signals Servicing Survey.
(c) Flight Refuelling.
(d) Planning of Scale of Operational Effort.
(e) Engine Supply Requirements.

Manpower Requirements for 'Window' Launcher

In the early months of 1945 an operational trial of the Fairey Mark I 'Window' Launcher was carried out at R.A.F. Station, Little Staughton. This machine was designed for use in disseminating conducting strips of aluminium foil from aircraft on operational trips for the purpose of confusing enemy radar. Simultaneously with the operational trial the manpower requirements for the Launcher were investigated.

The operations to be performed in loading the launchers were :- withdrawal of bundles of 'Window' in transit cases from store, conveying the 'Window' to aircraft, loading the launcher with 'Window' and returning transit cases to the store. This work and the servicing of the moving parts of the launcher mechanism were done by a specially established 'Window' party. The remaining additional work caused by the new installation arose when it was necessary to remove parts of the launcher in order to service faulty radar boxes; this work was done by the riggers.

The object of the manpower investigation was to determine the size of the 'Window' party required for the job and the amount of additional work which the riggers would have to do. This object was successfully achieved by suitably modified use of the standard recording methods[(1)] with the service of three N.C.O. recorders for nine days.[(2)] It is noteworthy that this was perhaps the first occasion on which the manpower requirements for a new piece of equipment were investigated thoroughly at the trial stage and further that these requirements could be determined in a comparatively short time.

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(1) See previous section - 'The Work of Recording Parties'.

(2) 'The Operational Trial of the Fairey Mark I Automatic "Window" Launcher'. Bomber Command O.R.S. Report No. 134 dated 3 July 1945. (A.H.B./II/39/1).

/ Signals

Signals Servicing Survey

Towards the end of the European war, the Signals Branch at Bomber Command set up a Signals Servicing Committee to report on the organisation required for servicing airborne radar equipment in a heavy bomber force. In the course of its enquiries, this committee made a critical examination of the existing signals servicing organisation at a very large number of R.A.F. units. In order to supplement the information compiled in this way at first hand, a signals servicing questionnaire was sent out to Group Headquarters, Base and Stations within Bomber Command. O.R.S. advised on the formulation of the questionnaire and made a statistical analysis of the replies.[(1)]

Flight Refuelling

At the request of the Operations Branch, O.R.S. undertook, in January 1945, some work on flight refuelling of potential usefulness in planning for the Far East theatre. The work involved estimating for certain stated conditions how the maximum possible weight of payload carried by a bomber to be re-fuelled once *en route* would vary with the position of the refuelling point.

In the first piece of work,[(2)] the bomber was assumed to have a Basic Weight of 41,500 lb. and a Maximum Permissible All-Up Weight (A.U.W.) of 68,000 lb. and was to fly 1,500 miles to its target and 1,500 miles back to the same base during an operational sortie. The weight of the payload was given by the condition that the sum of the weight of the payload, fuel and any overload fuel tanks should equal the difference between the Maximum Permissible A.U.W. and Basic Weight at the time when most fuel was aboard. With these conditions and knowledge of the fuel consumption of Lancasters Marks I, II and III, a diagram was produced which gave the weight available for payload and any overload tanks for varying positions of the refuelling point.

In the second piece of work,[(3)] two cases were considered. In the first a diagram was produced similar in essentials to the one mentioned above but giving information for sorties of various lengths. In the second case a diagram was produced which in its turn was essentially similar to the one produced in the first case except that allowance was made for the fact that the Maximum Permissible A.U.W., while it could not exceed 68,000 lb. before take-off, could rise 70,000 lb. after take-off.

(1) 'Report on the Servicing of Radio Equipment used in Heavy Bomber Aircraft by Bomber Command Signals Servicing Committee'. Bomber Command File S.32430 (1 June 1945).
(2) 'A Problem in Flight Refuelling'. Bomber Command [redacted] Memo. No. 60 dated 13 January 1945. (A.H.B.2 unindexed).
(3) 'Extension of Problem in Flight Refuelling'. Bomber Command [redacted] Memo. No. 61 dated 28 January 1945. (A.H.B.2 unindexed).

Planning of Scale of Operational Effort

In planning the scale of effort and the aircraft and manpower resources required to back a given scale of effort it was necessary to know how many sorties each aircraft would fly during its life and how much periodical inspection work would arise. One of the determining factors in both these questions was the casualty wastage rate. As an aid to planning for Tiger Force, accordingly, O.R.S. undertook, at the request of the Nucleus Planning Staff, a study of the variations in the sortie output per aircraft and in the arising of periodical inspections when the casualty wastage rate took different values.

It was necessary, in order to obtain numerical results, to specify certain conditions, for example in respect of the periodicity of inspections and the relative amounts to be performed of operational and non-operational flying (for which the wastage rate would be different). The conditions assumed were those likely to obtain in Tiger Force.[1] The number of sorties flown for every major inspection performed was calculated for various casualty wastage rates and the number of, and manhours expended on, minor inspections to back a flying programme of any fixed number of sorties were each compared for various casualty wastage rates with the corresponding figures at zero casualty wastage.

Engine Supply Requirements

Another investigation, undertaken by O.R.S. for the Nucleus Planning Staff, had the object of obtaining an estimate of the number of engines required monthly per 100 U.E. aircraft operating under conditions likely to arise in the Far East. In particular, estimates were required for cases in which operational sorties of duration 7 hours, 9 hours and 13½ hours were flown.

The numbers of Merlin engines (fitted to Lancasters of Bomber Command) returned to maintenance units for reasons of unserviceability were compared with the average flying hours per sortie, month by month, over a period of six months. From this it was possible to estimate per returning (engine) sortie the number, c, of engines likely to be returned by the force to the repair depot for reasons of unserviceability in the three cases of different sortie lengths.

(1) 'The Effect of Wastage on Sortie Performance per Aircraft and on the Arisings of Major and Minor Inspections'. Bomber Command O.R.S. Report No. 138 dated 30 July 1945. (A.H.B./II/39/1).

/ Assuming

Assuming the probable policy with regard to engine replacements and the disposal and replacement of major-expired and written-off aircraft, formulae were developed for the number of replacement engines required per (engine) sortie in terms of the engine unserviceability rate, c, and the wastage rate. With the help of information about the probable flying intensity, engine unserviceability rate and wastage rate, the engine provisioning requirements could then be estimated.[1]

(1) 'Estimation of Engine Requirements for V.L.R. Sorties'. Bomber Command O.R.S. Report B.236 dated 16 May 1945. (A.H.B./IIH/241/22/12).

CHAPTER 21

HOLLERITH MACHINERY USED BY BOMBER COMMAND OPERATIONAL RESEARCH SECTION

Causes of Introduction

1. In November 1943, a new Raid Report pro forma, which gave considerably more detailed information than previously, was introduced. In particular, the pro formae which were completed by the Station Intelligence Officers for each individual sortie, detailed the special equipment carried by each aircraft.

2. Prior to the introduction of the new pro forma, analyses which were conducted to discover the efficacy of each equipment had been carried out on data obtained from specially designed questionnaires - one for each equipment. The new pro forma thus eliminated the necessity for the special returns and also gave additional information about the combinations of equipments carried, enabling, therefore, more precise investigations to be made. Furthermore, a new statistical method of analysing the data was introduced and this required figures broken down into fine divisions.(1)

3. To obtain figures in these small divisions, giving all the various combinations of equipments, it was clearly necessary to introduce some form of recording which gave the facts in an easily sorted manner. The Paramount card system involving the use of a small card with holes punched round the perimeter was, therefore, attempted. Each special equipment was given a specific hole as were the aircraft's group, type, mark and result. A card was taken in conjunction with each Raid Report and a portion of the card from the appropriate holes to the edge of the card was clipped out by hand and, for reference purposes, the squadron and letter of the particular aircraft was written onto the card. All figures were then obtained by needling off the cards required and counting them by hand.

4. As this method of recording suffered from two serious defects, namely, lack of speed and inaccuracy due to hand counting, attention turned to mechanical methods. Preliminary conversations with the British Tabulating Machine Company were held and a knowledge of Hollerith machines and their capabilities was obtained. It was decided that, apart from facilitating analyses which were already being undertaken, the introduction of this method of recording in which one card was punched for each

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(1) Bomber Command O.R.S. Report No. 113.

/ aircraft

aircraft would save personnel and also enable other investigations, which had been considered impossible previously owing to the time factor involved, to be made. O.R.C. were, therefore, asked to obtain for the section two punches, a mechanical verifier and a counter sorter.

5. The concurrence of the Treasury was obtained and after several meetings with the British Tabulating Machine Co. (B.T.M. Co.) who were told what information was required on the cards, a specimen card was drawn up. A Treasury official who attended one of these meetings stated that since the card was to contain a large amount of double punching, a mechanical verifier was not particularly apposite and suggested that an electrical verifier should be supplied instead. The original request was therefore altered and the machines demanded were:-

(a)	Counter Sorter	(Type 75, 80 Column)
(b)	Two Manual Punches	(80 Column)
(c)	One Electric Verifier	(80 Column)

Preliminaries (Training of Operators etc.)

6. Although the original cause of the introduction of this form of recording was the analysis of special equipments, it was obvious that assistance might be given in other sides of the sections work. A meeting at which a representative from each sub-section of O.R.S. attended was held and it was agreed that the card should carry most of the information given on the Raid Report as well as that concerning special equipment.(1)

7. Having decided upon the information which it was required to record, it was then necessary to establish in what manner the qualitative information was to be coded. The following broad principles were adopted in drawing up the code sheets:-(2)

(a) The amount of coding should be reduced to a minimum.

(b) In order to save time the coding was to be made on the original document.

(c) To save time in sorting, the number of columns in which double punching occurred was to be a minimum.

8. It was decided to alter the sections establishment and replace two L.A.C. posts by two L.A.C.W.s who were to be trained as punch operators by the British Tabulating Machine Co. Accordingly, two were posted to O.R.S. and then sent on

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(1) A full note of these questions which were recorded is given in Appendix 5, Form No. 1.

(2) The method of coding the original card appears as Appendix 5, Form No. 2 and Appendix 5, Form No. 3 is a specimen coded Raid Report.

/ three

three weeks course to the Company's Head Office in London. At the end of the course, the tutor returned with the trainees and spent a week teaching them to punch from actual Raid Reports.

9. Meanwhile, three clerks who had been engaged in the production of statistics by hand from Raid Reports were set to work on coding Raid Reports for practice purposes. They rapidly became accustomed to the work and, although at first their work was checked, it was found, after some time, only necessary to check their work at intervals. Subsequently, one clerk only was employed, being capable of coding about 600 Raid Reports per day, and it was necessary to check his work only after some major change had been made in the method of coding.

History of Raid Report Cards

10. When the operators had gained some practice in dealing with Raid Reports, work was begun in earnest on cards for the operations occurring on the night of 15/16 March 1944 and cards for most night operations were punched from then until the end of the war with Germany.

11. It was found after just over a month's work that the rate of operations was too great and that the cards were not being produced as expeditiously as required. A critical analysis was made to discover what information on the cards was used infrequently or not at all. These sections were found to be mainly those devoted to recording if special equipments were used or were unserviceable, which could not be analysed owing to inaccuracy of reporting and to the Heading and Indicated Air Speed at bombing. These sections were then deleted from the card and this reduced the length of card from 59 columns to 42 columns.(1) This step together with the omission of cards for operations of the minelaying or light Mosquito type of attack enabled the work to be completed more rapidly.

12. In June 1944, however, the rate of operations increased still further and in order to offset this it became necessary to obtain two more punch operators (L.A.C.W.s obtained on Laboratory Assistant Establishment). Subsequently the cards were generally produced on the average two to three days after the Raid Reports were received or six to eight days after an operation.

13. At the beginning of May 1944 it was found essential owing to operational necessity to investigate the losses of aircraft with Monica equipment(2) and as a

(1) A comparison of Appendix 5, Form No. 2 and Appendix 5, Form No. 4 will show the precise differences between the cards used.

(2) Bomber Command File S.28806/2.

/ certain

certain amount of doubt existed about the accuracy of the original data, it was decided to make two lists of aircraft by means of a Tabulator. The list detailed over a month the special equipment carried by Date, Target, Squadron and Aircraft letter whilst the other, over the same period, gave the same information by Squadron and Letter. From the latter list it was possible to trace the history of each aircraft throughout the month. By glancing down the equipment detailed for each aircraft it was possible to check the accuracy of reporting on the assumption that the special equipment carried by a particular aircraft normally did not vary much from night to night. If any errors were found then the appropriate corrections could easily be made in the list by date and target. Thus for this list more accurate data on the sorties and missing of aircraft with various combinations of equipments could be obtained.

14. Prior to this date all statistics on special equipment had been obtained by sorting and counting. The use of the tabulator in this particular instance, however, indicated that more results could be obtained from the same data by using more intricate machines. Accordingly, with the help of the British Tabulating Machine Co., an arrangement that O.R.S. should have the loan of their machines for two or three hours per fortnight was made with the Ministry of Food (Potato and Carrot Division) whose Hollerith section contained such machines. In July 1944 it was found that this arrangement was not particularly satisfactory and new arrangements were made so that O.R.S. should use the machines at a British Tabulating Machine Co.'s Service Bureau.

15. The Hollerith Section was committed to the production of data at fortnightly intervals for the analysis of special equipment. For this purpose it was found desirable to obtain a list of aircraft detailing the special equipments carried by, date, target, squadron and aircraft letter and also figures giving sorties and missing of each class of aircraft carrying a particular combination of special equipment. It was found desirable to produce these latter statistics also from the tabulator. Unfortunately, the system of coding special equipment then employed did not easily lend itself to the use of a tabulator as it involved punching more than one hole in the columns for special equipment, and the tabulator could not print this. The method of coding special equipment was, therefore, altered on 14/15 August 1944 to produce only single punching.(1)

(1) See Appendix 5, Form No. 5.

/ For

16. For the analysis of the accuracy of results achieved in bombing it was found necessary to prepare a list giving the plotted position of each aircraft's photograph by bombing times. This was originally done by hand from two sources - the Raid Reports for the times and methods of bombing and from a Photographic interpretation list giving ranges and bearings from the Aiming Point. It was readily obvious that the Hollerith Section could assist by providing a list of aircraft by bombing times indicating the method of bombing. The system of coding the bombing technique was such that double punching occurred and it was therefore deemed advisable to give an extra column to this question on the Raid Report. The coding was therefore altered (1) and the new card introduced on 1 November 1944.

17. During a visit from a member of VIIIth U.S.A.A.F. it was discovered that at their H.Q. a complete set of American Hollerith machines existed. As this was much nearer than the Service Bureau, permission was obtained at the beginning of 1945 for use to be made of these machines. It was not possible to use their machines for all O.R.S. work owing to the American method of punching alphabetical information - 3 zone instead of 2. (2) Work, however, was greatly facilitated by this concession.

18. Towards the end of the war with Germany so many new equipments had been introduced that it became necessary to alter the method of coding special equipment in order to avoid double punched columns and so still produce a special equipment tabulation. This new card was introduced on 15/16 March 1945 and used until the end of the war.(3)

History of Other Cards

19. It had originally been intended to put onto the card punched from the Raid Reports, information from three other sources:-

(a) Combat reports - giving information concerning attacks by enemy aircraft on our own.(4)

(b) Damage reports - showing the extent of damage to our aircraft.(5)

(c) Photographic Interpretation Plottings - showing the plotted position of an aircraft's photograph which had been taken with bombing.(6)

(1) See Appendix 5, Form No. 6.
(2) See Appendix 5, Form No. 2.
(3) See Appendix 5, Form No. 7.
(4) See Appendix 5, Form No. 8.
(5) See Appendix 5, Form No. 9.
(6) See Appendix 5, Form No.10.

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The intention had been to obtain the appropriate Raid Report cards from their file and punch onto the card the fresh information. In order to facilitate the pulling of the Raid Report card, the verifier after having checked the card wrote the squadron and aircraft letter onto the card. It was found, however, that considerable time was lost in this manner and as the same result could be obtained by passing the cards through an 'Interpreter' this procedure was dropped. Furthermore, it was not found practical to punch this new information onto the original cards in the first few months owing to the shortage of available labour. This meant that when enough staff was available a large amount of back work remained and that some other method of putting the fresh information onto the Raid Report cards was required.

20. After some consideration it was decided to punch each of three new sets of information of three new cards. By sorting these into the same sequence as the original file of cards and then passing both files through a 'Collator' it was possible to extract from the larger file of Raid Report cards all the cards corresponding to those in the smaller file of Combat cards, Damage cards and Photo cards. It was not necessary to do this in three stages involving the collation of the large file three times as the three types of cards were easily separated from one another. Thus, in the first collation they would be sorted together and all the cards which required either combat, damage or photographic information would be obtained. Thereafter, it was only necessary to deal with the smaller file of cards and, by means of three collations with the combat, damage and photographic cards separately, it was possible to obtain the cards required. As both master pack and the detail pack were in the same order the cards could immediately be passed through a 'Reproducer' and the new information automatically copied off the new cards onto the old. Owing to the fact that the method of designation involved the use of the aircraft letter whilst the collator was strictly a numerical machine, it was necessary to divide the collation into three parts - one part for each section of the alphabet. Although this method was decided upon and the greater part of the cards for new information were punched it was never possible to put this method into operation owing to the fact that the machine time available at the Service Bureau only allowed the more necessary immediate analyses to be completed.

/ In

21. In the autumn of 1944, the number of escaped and returned aircrew had increased to such proportions that some new method of recording the data was required. It was decided that by using the Hollerith much time would be saved. Full details of the method of coding and the information obtained from these cards is contained in and a Master Code Sheet is attached at Appendix 5, Form No. 11. When the war with Germany ceased and P.O.W.s were returning home it was decided to extend this system to cover the Interrogation reports obtained from each crew member. It was found, however, that the system in use employed a vast amount of double punching and although this was no great hindrance when small numbers of cards were involved it was likely to prove so when handling 10,000 cards as no great use could be made of machines other than the 'Sorter'.

22. The system of coding was therefore altered to meet this requirement but in order to enable all the information required to be recorded it was necessary to use two cards. As a considerable part of each card was duplicate information it was decided to produce three cards - one a General card for the duplicate information and the other two (Casualties and Damage) cards bearing the remaining information. The duplicate information was then to be transferred onto both the Casualties and Damage cards to give the final cards required.(1)

23. To obtain accuracy in coding, each story was coded twice. A 'check coder' then compared the two codings and if a discrepancy was found recoded the informatio from the original story. Each card was then passed through the sorter counting on every column and, in order to check that the data was consistent, various cross checks made on the figures obtained. This process caused much wear to the cards and therefore, the final cards, were produced on entirely blank cards. A card for aircraft from which there were no survivors was also punched and the sections corresponding to the final cards for survivors being reproduced onto the same type of cards.(2)

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(1) Details of the cards and the method of coding are at Appendix 5, Form No. 12.

(2) Full details of this reproducing process are given in Appendix 5, Form No. 13.

/ Some

Some Results Obtained from Raid Report Cards

24. Although some of the results obtained have been mentioned in preceding paragraphs full details are given below for these results as well as for other major results obtained from the Raid Report cards.

Special Equipment Analysis

25. For this both a list and a tabulation was required. The list gave special equipment and result of the mission in coded form by date, target, squadron and aircraft letter, and the sorties made by each squadron was simultaneously obtained. The list facilitated reference to the special equipment carried by a particular aircraft. The tabulation gave the number of aircraft despatched and missing for each combination of special equipment by date and target. From this it was therefore easily possible to perform the calculations necessary to complete an analysis along the lines of O.R.S. Report No. 113 and to estimate the efficacy of each special equipment.(1)

Timing Distribution

26. Time Distributions were used for two main purposes. A list of aircraft by time giving the method of bombing was required and this in conjunction with information showing the plotted position of photographs was used in analysis conducted into the relative merits of different bombing techniques. Concentration in time was also considered important in reducing fighter losses and information showing the number of aircraft bombing in each minute of an attack was required. In consequence a tabulation giving the number attacking the target in each minute of a raid was made and from the figure obtained it was possible to see if the raid had been carried out as planned.(2)

Height Distribution

27. From some investigations made to discover the cause of aircraft losses a distribution indicating the number of each aircraft attacking at each height band was found useful. From this it was possible to see whether the planned distribution was maintained and also, by means of this and a timing distribution, the incidence of collisions and the concentration of 'Window' could be estimated.

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(1) Specimens of both the list and tabulation can be seen in Appendix 5, Form No. 14.

(2) The figures obtained in this manner form the basis of O.R.S. Reports Nos. B.233 and B.235. (A.H.B./IIH/241/~~22~~/12).

/ Losses

Losses by Makers of Aircraft etc.

28. When it was discovered that aircraft with the Nitrogen Tank equipment had higher losses than expected a full investigation into the possible causes was made. As this investigation involved splitting the cards on the Aircraft Serial Number, it was decided to discover what other differences existed between two sets of data obtained in this manner. It was found that certain sets of aircraft split in this manner had two other main differences apart from Nitrogen Tanks. One being that the manufacturers were different and the other that a larger proportion of aircraft were equipped with Merlin XXIV engines as well as with the special tanks. By sorting the cards on serial numbers it was possible to split the aircraft by makers, engines and tanks and thus a full investigation could be made. The results indicated the apparent higher losses of the nitrogen tank aircraft could be more accurately described as due to Merlin XXIV engines.

29. It was also possible by sorting on Serial Numbers to investigate the usefulness of glossy paint in avoiding being held in searchlights. An insufficient amount of data was obtained to justify any conclusion.

Distribution of Experience

30. Investigations had been made at various times by O.R.S. into the effect of pilots experience on the missing rate. After the inception of the Hollerith section those figures were provided directly from the Raid Report cards by sorting the cards into experience groups by date, target and group and then counting on the result column to provide sorties and missing. The investigation was completed by using the same statistical methods as were used for analyses of special equipment.

Abortive Sorties

31. The Raid Report cards provided a ready source of information for investigation into the effect of weather and icing on the abortive sortie rates. This information was used to estimate the economic weight of de-icing equipment.

Bomb Load

32. At various times O.R.S. had been asked to discover if the carrying of certain types or loads of bombs was subject to special risks. The data for each operation showing loss rates by types of bomb load were easily obtained from these cards and investigations, showing null results, were made.

/ Night

Night Raid Report Tables

33. One O.R.S. commitment was the production of a report on each night's operation. An appendix to this report was a table giving a breakdown by target, group, aircraft type and mark which showed for each subdivision the number of aircraft despatched, attacking the primary or secondary target, abortive and missing as well as the number of those damaged and intercepted. The first half of this table - numbers despatched, attacking etc. - was obviously easily obtained from the cards in the required breakdown.

Results obtained from Interception and Damage Cards

34. As stated in para. 20 above, these cards were punched in order to put information concerning aircraft damaged or intercepted onto the corresponding Raid Report cards. It was hoped in this manner to collate information obtained from special returns for these aircraft with that given on their Raid Reports. For reasons, also given in this paragraph above, it was never found practicable to collate the additional cards with original cards and, up to the time of writing, these cards have not been used in any analysis.

Results obtained from Photographic Cards

35. Although providing mainly for the purpose of putting photographic information onto the main cards, after the end of the war it was found necessary to investigate the trends in bombing accuracy throughout the war. It was proposed to do this by calculating a parameter for each major raid from 1942 to the end of 1944 and, to this end, cards were punched for each aircraft with a plotted photograph on any of the selected operations. As this investigation is probably the most representative example of statistical calculations done by O.R.S. using Hollerith machines, the procedure given is more detailed than that in the previous paragraphs.

36. As in Bomber Command O.R.S. Report No. 127 (1) the distribution of bomb fall, or in this case photoplots, has been assumed to consist of two parts, being in part a normal distribution and in part a totally different distribution consisting of gross errors which may overlap the normal distribution. The method of eliminating the gross errors and in obtaining a parameter - the standard radial error of the distribution - is given fully in the Report quoted above and the manner in which this method has been adapted for Hollbrith purposes is given below.

(1) A.H.B./II/39/1.

/ As

37. As can be seen from Appendix 5, Form No. 10, the only information showing the position of the photograph was given as a range (r) and a bearing (θ) from the detailed Aiming Point.

Calculation of M.P.I. of Photographs

38. It was first necessary to calculate the mean point of the photographs from the data given on the cards. The cards were sorted into order on the θ columns and each group or cards for each value of θ (0° - 360°) was preceded by a master card giving for that angle the value of θ, sin θ and cos θ. The whole file of cards was then passed through a 'Reproducer' and the appropriate signs for sin and cos were master gang punched onto the detail cards. The cards, still in the same order, went next into a 'Multiplier' where the following calculation was done - $r \times \sin\theta = x$ and $r \times \cos\theta = y$ to give the Cartesian Co-ordinates of the plotted position with respect to the Aiming point. After being sorted into date and target sequence the cards were passed through a Tabulator and the totals Σx, Σy, and Σ with appropriate signs was obtained. The calculation $\bar{x} = \frac{\Sigma x}{\Sigma}$ and $\bar{y} = \frac{\Sigma y}{\Sigma}$ then gave the M.P.I. in cartesian co-ordinates.

Elimination of Gross Errors and the Calculation of σ 2

39. A master card for each operation giving $\bar{x}$ and $\bar{y}$ as well as indicative information was punched. After collating these into the main file with the θ master cards removed, the cards passed through a tabulator where the following calculations were performed on every card:-

$|x - \bar{x}|$ and $|y - \bar{y}|$ and the results summary punched onto new cards. By gangpunching, after sorting into values of $|y - \bar{y}|$, the value $(y - \bar{y})^2$ was obtained. The Multiplier then performed the calculation $(x - \bar{x})^2 + (y - \bar{y})^2$ $(= R^2)$. Thus, each new card bore the square of the distance of the plotted position from the mean point.

40. A new tabulation was then made by operation in which after each card had been fed into the machine the following was printed:-

R^2 ΣR^2 and Σ

The gross errors were eliminated by neglecting the distribution as soon as $\Sigma R^2 \geqslant K . R^2 . \Sigma$ and the value taken for σ^2 was $k^1 \times R^2$ at this point (for the actual value of k and k^1 see the Report quoted).

/ P. O. W.

P. O. W. Cards

41. The full details of information obtained from these cards are to be found in

Difficulties Encountered

42. Several difficulties in running a Hollerith section for O.R.S. work occurred. The most important of these were the following:-

(a) The slow punching and verifying speeds obtained.
(b) Machines other than those actually in O.R.S. were not easily obtainable, and these had to be adapted owing to the complicated nature of O.R.S. work.
(c) Changing requirements caused major changes in the manner of coding on the cards.
(d) Inaccuracies in the data.

(a) Slow Punching Speeds

43. This was partly due to the employment of personnel who were not selected but posted in for punching work. This work was of a tedious nature and not everyone was capable of doing such work. Apart from this, none of the documents were received in a form particularly suitable for punching. The form of the documents had been fixed before the Hollerith was introduced and no major changes were possible, as this would not have suited the other users of the reports. Had it been possible, to (a) choose the operators and (b) adapt the form of the documents received to one suitable for punching, the rate of production of the cards would doubtless have been increased.

(b) Lack of Machines

44. There were many occasions when it was required to produce information from the cards in the form of a list, or by a complicated breakdown. A tabulator would have been particularly useful for these purposes, but the amount of Tabulator time required by O.R.S. was insufficient to warrant the introduction of such a machine. Unless the information required was of sufficient magnitude, it was not economical to make a special visit to the Service Bureau and so the work had to be delayed until the normal visit to the Bureau was due, or alternatively had to be completed by hand, assisted wherever possible by the Sorter. Furthermore, although Hollerith machines are very suitable for some types of statistical calculations and recording, nevertheless, since they have been primarily intended for accounting, it will be readily seen that it is sometimes necessary to adapt a machine and use it in a manner other than that originally intended.

/ (c)

(c) Coding Changes

45. As can be seen from the preceding paragraphs on the History of the Hollerith Section a number of major changes were made in the method of coding. Apart from the first change, which was due to insufficient staff, all the other alterations were occasioned by the necessity of using machines other than those originally intended for the production of statistics from the cards. It is obvious that any changes in the manner of coding information can cause many difficulties. It is advisable, therefore, when drawing up the card for long term analyses, to try and use a method of coding from the outset which allows a certain amount of flexibility in the use of machines and also leaves sufficient space for additional codings which may arise subsequently. To obtain flexibility in the use of machines it is advisable to avoid double punching as much as possible.

(d) Inaccurate Data

46. It was found by comparison with special returns that the Special Equipment given in Section 'A' of the Raid Report was not always accurate and, as mentioned in para. 13 above, it was attempted to correct the information by means of lists obtained on a Tabulator. This course, however, did not give a complete check and the only really accurate method was to compare all the special returns received by other branches in the Headquarters with the Raid Reports. This was done for some equipments in some periods but, owing to the enormity of the task, it was not possible to make a thorough check. Another difficulty was due to the fact that sometimes two and sometimes no Raid Reports were received for an aircraft. Several attempts were made to remedy the situation, but none were completely successful. These cards, therefore, were never 100 per cent accurate and, although, in general this only reduced the significance of the result obtained from them, it made certain investigations involving small samples impossible.

Extension of Hollerith Work

47. As mentioned in para. 44 above, O.R.S. did not have enough commitments to warrant the introduction of machines other than the Sorter/Counter. There were many records being kept in Bomber Command Headquarters which could probably have been kept more economically on a punched card system, controlled by a Central Statistical Section. This Central Section, which would require a full complement

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of Hollerith machines, would keep any statistics required by more than one section in the Headquarters and a large part of the information required for Operational Research would be provided by that source. The introduction of such a Section would eliminate much duplication of effort and would enable various returns to be easily collated to ensure accuracy, as well as making available to all sections, all types of Hollerith machines.

48. A Central Statistical Section would also obviate the necessity of calling for large numbers of over-lapping returns and would also be able to ensure that, whenever the same information was received from two different sources, they were consistent. Inconsistency and the incorrectness of data was a serious difficulty encountered by O.R.S. A few examples of the type of information which could be recorded easily on punched cards are given below:-

(a) Aircraft states.
(b) Personnel Postings.
(c) All statistical cards required for each operation (obtainable from a Raid Report with very few more questions than that used at the end of the war).
(d) Engineer Records of Failures and Flying Hours.

It is worthy of note that the American VIIIth U.S.A.A.F. did in fact keep a Central Statistical Section employing punched cards and provided data on several of the above.

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APPENDIX No. 1

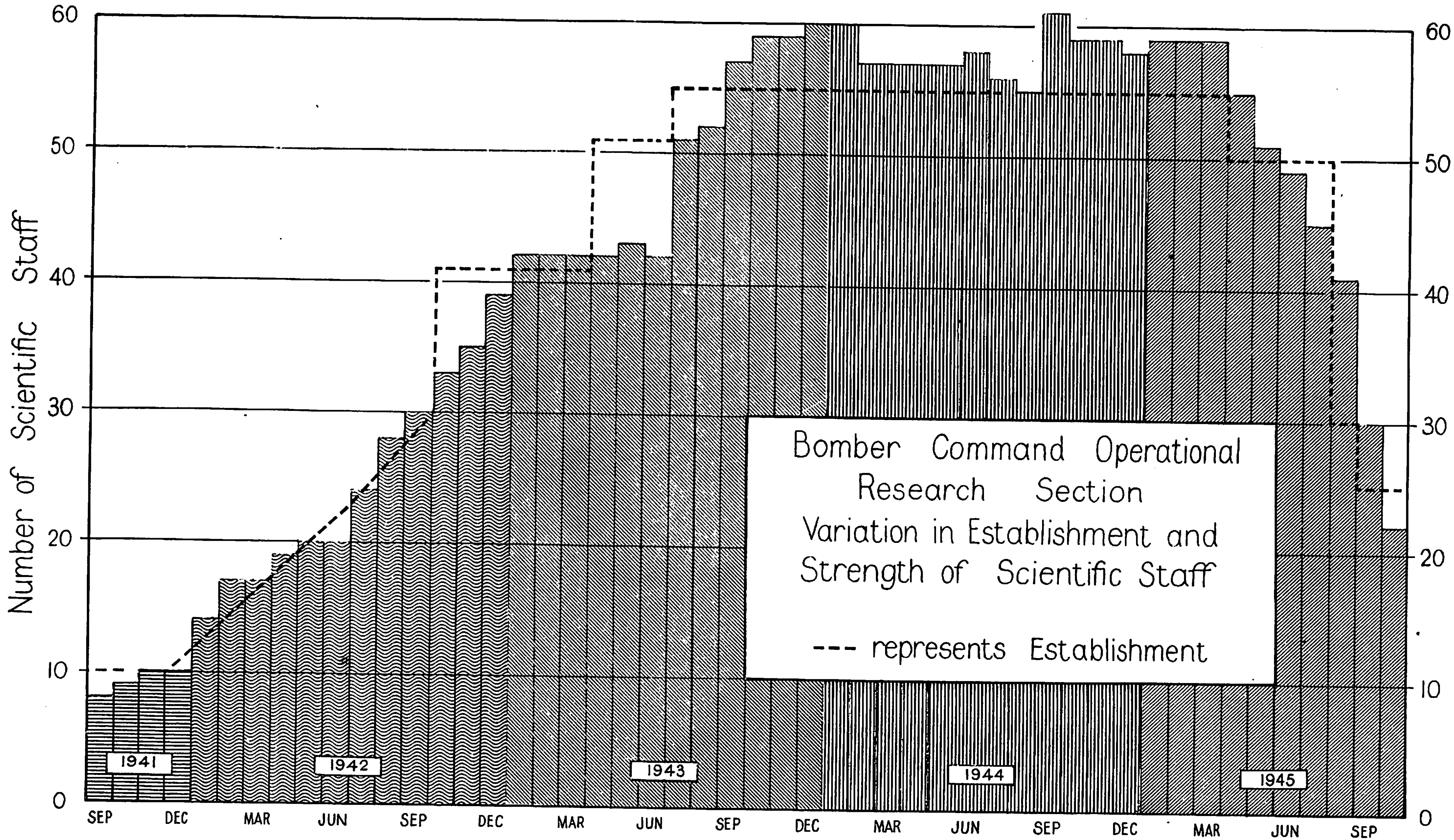
BOMBER COMMAND O.R.S. - PERSONNEL

Name	Date of Arrival	Date of Departure	Main Duties in Branch
Mr. H.L. Beards	Nov. 1941	Dec. 1945	Bombing Accuracy; Weapon Effectiveness; i/c O.R.S.1(d); B.A.U.; i/c B.C.B.R.U.
Mr. E.B. Beadle	Jan. 1942	July 1942	Losses analysis.
Mr. S.C. Britton	May 1942	Aug. 1945	Losses analysis; later i/c O.R.S.2(b) (R.C.M.).
Mr. T.F. Brown	Nov. 1942	Sept.1945	Damage Inspector No. 3 Group.
Mr. K. Butler	Dec. 1942	Oct. 1945	Research on Radar protective devices.
Mr. E.R. Barker	July 1943	Aug. 1944	Losses analysis.
S/O. M.M. Benton (now Sovig)	Sept.1944	May 1945	Radio Aids to Navigation.
Mr. W.W. Corbett	Oct. 1941	Aug. 1945	Research on Visual Identification; later Admin. Officer.
Mr. J. Curry	Feb. 1942	July 1945	Radio aids to navigation; losses analysis; O.R.S. No. 5 Group.
Mr. G. Calcutt	Feb. 1942	Oct. 1942	Losses analysis; Records.
Mr. N.C. Cook	Dec. 1942	Oct. 1945	Photographic aspects of Raid Effectiveness.
Mr. J.D. Carthy	July 1943	June 1946	Raid Effectiveness Analysis.
Mr. I.J. Campbell	July 1943	July 1946	Losses Analysis; Manpower investigations.
Mr. R.H. Collcutt	Sept.1943	Nov. 1945	Weapon Effectiveness; Bombing Accuracy; Bomb Damage Survey.
S/Ldr.R.G.W.Croney	Sept.1944	June 1946	Radio Aids to Navigation; later i/c O.R.S.5.
Mr. D.N. Davies	Oct. 1943	Oct. 1945	Radio Aids to Navigation; H.2.S. Mining.
Mr. F.J. Dyson	July 1943	Sept.1945	Theoretical Investigations concerning losses.
Dr. B.G. Dickins	Sept.1941	Sept.1945	O. i/c O.R.S.
Mr. W.A. Eyre	Dec. 1942	Sept.1945	Damage Inspector No. 4 Group.
Mr. B.P. Emmett	Sept.1943	Oct. 1944	Manpower Investigations.
Mr.J.E.Fothergill	Oct. 1942	Jan. 1946	Losses Analysis; later i/c O.R.S.3.
Miss J.M.M. Goggin	Sept.1941	Nov. 1945	Monthly review of Bomber Losses; i/c O.R.S.3., later i/c O.R.S.2.a.
Mr. P.M. Game	Aug. 1942	Aug. 1945	Navigation Research.
Mr.C.W.Grove-White	Oct. 1942	Mar. 1943	R.C.M. Research.
Mr. H.R. Gregory	Jan. 1943	Sept.1945	Damage Inspector H.Q., B.C.

Name	Date of		Main Duties in Branch
	Arrival	Departure	
F/Lt. Guinand	Feb. 1943	June 1943	Oboe Investigations. Canadian Attachment
Mr. W. Guy	May 1943	Sept.1945	R.C.M.; Bombing accuracy analysis.
Mr. G. Harris	July 1943	Sept.1944	H.2.S. Research. Canadian Attachment.
Mr. W.V. Hobson	Sept.1943	Aug.1944	Radio Aids to Navigation.
Mr. J.W. Hopkins	Jan. 1944	Mar. 1945	O.R.S. No. 6 Group. Canadian Attachment.
F/O. R.E.Hemmings	Feb. 1945	Jan. 1946	Navigation Research.
F/Lt. J.M.Hyslop	Feb. 1945	Sept.1945	Mathematical Study of Bombfall distributions.
Mr. J.A. Jukes	Sept.1941	Oct. 1945	Radio Aids to Navigation; O.R.S. B.D.U.; O.R.S., P.F.F., B.C.B.R.U.
F/Lt. Kershaw	Mar. 1945		O.R.S. No. 6 Group. Canadian Attachment.
Mr.B.A.Loveridge	Aug. 1944	Dec. 1944	Oboe Research.
Mr. W.R. Lund	Sept.1943	Apr. 1945	Radar Protective Devices.
Mr. S.V. Lindley	Aug. 1943	Jan. 1944	Raid Effectiveness Analysis.
Mr. F.J. Lloyd	Nov. 1942	July 1945	Losses Analysis; O.R.S. No. 4 Group.
Mr.L.F.Lammerton	Jan. 1942	July 1945	i/c O.R.S.2.b.; later O.R.S. No. 100 Group
Mr. E.A. Lovell	Sept. 1941	Apr. 1951	Vulnerability Research; i/c O.R.S.2c; attached B.R.U., B.C.B.R.U.
Mr. L.C. Luckwill	July 1942	Aug. 1945	Raid Effectiveness Analysis; later i/c O.R.S.1.a.
Mr. B.R.S. Megaw	Jan. 1942	Oct. 1945	Editor Bomber Command Quarterly Review.
Mr. H.P. Moon	July 1942	Feb. 1943	Raid Effectiveness Analysis.
Dr. A.F. Munro	July 1942	Aug. 1943	Night Vision Research.
Mr.W.J. Mayo-Wells	Aug. 1942	Feb. 1944	Radio Aids to Navigation; Airfield Control.
Mr. J.K. Marshall	Oct. 1942	July 1946	H.2.S. Research; B.D.U.
Mr. M.L. Meyer	Oct. 1942	July 1945	Bomber Command Night and Day Raid Reports.
Mr. J.C. MacCallum	Sept.1943	Oct. 1945	i/c O.R.S.2.d.
Mrs.S.G.R.MacCallum	Sept.1944	Oct. 1945	Analysis of fate of missing aircraft.
Mr. N.M. Mowatt	July 1943	Mar. 1949	O.R.S., B.D.U.
Mr.J.V.T.Matthews	July 1943	Feb. 1944	Raid Effectiveness Analysis.
F/O. J. McDonagh	Jan. 1945	Aug. 1946	Practice Bombing Analysis.
Miss K. O'Riordan	Apr. 1942	June 1942	Loss Analysis.
Mrs. E.M. Owen	June 1942	Feb. 1945	Day Raid Analysis; Bombing Accuracy, Losses Analysis.

Name	Date of		Main Duties in Branch
	Arrival	Departure	
Mr. D.C. Owen	Aug. 1942	1945	Vulnerability Statistics.
Mr.M.W.B.O'Loughlin	July 1943	Jan. 1946	Losses Analysis.
Mr. J.D. Oates	July 1943	Jan. 1946	Vulnerability Research.
Dr. B.G. Peters	Mar. 1943	Sept.1945	i/c O.R.S.1.a.; later i/c O.R.S.1.
Mr. A.W. Pratt	Dec. 1943	Aug. 1946	O.R.S. No. 1 Group.
Mr. B.M. Pocock	Oct. 1943	April 1945	Manpower Researches.
Mr. B.B. Parrish	July 1943	Apr. 1945	Practice Bombing Analysis.
Mr. G.A. Roberts	Sept.1941	Feb. 1945	i/c O.R.S.1; later i/c O.R.S.5.
Mr. R. Ross	Feb. 1942	Oct. 1945	Bombing Accuracy and Effectiveness.
Mr. W.D. Richards	July 1942	July 1944	i/c O.R.S.3.
Dr. R.J. Smeed	Sept.1941	Feb. 1947	i/c O.R.S.2.
Mr. G.W.H. Stevens	Sept.1941	May 1945	Visual Identification and Training Problems; i/c O.R.S.1.c.
Mr. A.H. Snowdon	Jan. 1942	Nov. 1942	Effectiveness of A.A. Fire.
Miss Smeaton	Apr. 1942	Aug. 1942	Losses Analysis.
Dr.J.K.St.Joseph	July 1942	Sept.1945	Night Photographic Research.
Mr. T.E.Shrimpton	Aug.1942	July 1945	Bombing Accuracy; Manpower Research.
Mr. J.L.H. Scott	Sept.1942	July 1946	Damage Inspector No. 5 Group.
Mr. K.A. Stott	Nov. 1942	May 1945	Manpower Research i/c O.R.S.6.
Mr. N. Sovig	Jan. 1943	Mar. 1945	Navigation Research.
Miss H.E. Scarth	June 1944	Sept.1945	Raid Effectiveness Analysis.
Mr. J.G.H. Stutt	Sept.1944	Sept.1945	Oboe Research.
Mr. J.W. Saunders	Sept.1944	Apr.1945	Raid Effectiveness Analysis.
Miss M.I. Scott	Sept.1944	June 1945	Raid Effectiveness Analysis.
F/O. G.T. Smailes	Sept.1944	Oct. 1946	Manpower Research.
Dr. J. Thewlis	Sept.1942	Sept.1944	i/c Radio Aids to Navigation Research.
Mr.J.G.Wardrop	Aug. 1942	Aug. 1947	Statistical Study of Losses.
Mr. F.C. Watts	Jan. 1943	Feb. 1944	Radio Aids to Navigation - R.C.M.

Appendix 2



Bomber Command Operational Research Section
Variation in Establishment and Strength of Scientific Staff
--- represents Establishment
Number of Scientific Staff
0
10
20
30
40
50
60
1941
1942
1943
1944
1945
SEP
DEC
MAR
JUN
SEP
DEC
MAR
JUN
SEP
DEC
MAR
JUN
SEP
DEC
MAR
JUN
SEP
DEC
MAR
JUN
SEP

APPENDIX No. 3

FORMS USED FOR RECORD OF AIRCREWS OBSERVATIONS

The attached forms were used for the recording of aircrew observations intended for use in operational research. They were filled up at the interrogation of the crew after an operation, usually by a specialist officer from details either recorded during the flight or memorised.

It was frequently possible to include considerable detail on these forms by the use of certain recognised abbreviations. Thus, the following symbols were used to record contacts observed on Fishpond or Visual Monica.

A.	Contact within 1 mile.
B.	Contact behaving suspiciously.
C.	Combat developed.
VF.	Contact identified as friendly by sighting.
EV.	Contact lost by evasive action.
P.	Contact passed away.

When a combat took place supplementary detail was provided in the Combat Report prepared by the Gunnery Officer at the Squadron.

The use made of the several attached forms was as follows.

Form No. 1	Early reports on G.L./G.C.I. Boozer. One Report Form for use by each aircraft.
Form No. 2	Later report form for Triple Channel Boozer. One report for use by each aircraft.
Form No. 3	Report on AI Boozer. One form used for the squadron.
Form No. 4	Report on Aural Monica. One form for use by the squadron.
Form No. 5.	Early form for Visual Monica, introduced into No. 5 Group, one form for use by each aircraft during the period of experimental development of the visual presentation.
Form No. 6	Later form for Visual Monica, one form for use by the squadron. In the final version, the 'Remarks' column was included a statement of the number of operations performed with the device by each operator.
Form No. 7	Early Fishpond report, one form for use by each aircraft.
Form No. 8	Later Fishpond report, one form for use by the squadron. The column left for recording of the number of contacts observed at some selected locality or time underwent several changes and was finally deleted. In the final version an indication was given of the number of operations performed with the device by each operator.
Form No. 9	A.G.L.(T) report as used throughout almost the whole operational history of the device, one form for each aircraft.
Form No.10	A.G.L.(T) report as coming into use at the end of the war, one form for use by the squadron.

APPENDIX No. 3

Form No. 1

COUNTERMEASURE 'BOOZER' QUESTIONNAIRE

(To be completed and despatched to H.Q.B.C. marked 'for attention of O.R.S.' after each operation)

Squadron No. Date of Operation Name of W/Op:

A/c Letter: Target:

Time at which lamp lit up	Behaviour of lamp, e.g. Steady, Intermittent	For how long did lamp remain alight ?	Place	Height	Was evasive action taken ?	Did Flak, S/L.s or Fighter Attack follow the lighting of the lamp ? If so, how long afterwards ? Give all other details	Other Remarks

APPENDIX No. 3

Form No. 2

'BOOZER' REPORT

Date: Pilot: Squadron:

Target: W/Op: A/c Letter:

Time	Type of Indication (D, B or Y)	Duration	Height	Position	Observations (Flak, Fighters, S/L seen, etc)

Form No. 3

REPORT ON AI 'BOOZER' INDICATIONS

Date: Target: Squadron:

A/C Letter	Time	Position	Height	Duration of Indication	Was indication associated with a sighting of an E/A	Indications associated with visuals of E/A			
						Type of E/A	Was indication received before or after sighting	Direction of approach and range of E/A when sighted	Did E/A Attack

APPENDIX No. 3

APPENDIX No. 3

Form No. 4

MONICA 'WARNING' RETURN

Target: Date: Station:

A/c Letter and Squadron	No. of occasions on which Monica Warning was received		
	British A/c seen	Enemy A/c seen	A/c causing warning not seen or not identified

Any remarks by Int. Officer, Squadron Commander, etc:

APPENDIX No. 3

Form No. 5

No. 5 GROUP VISUAL 'MONICA' REPORT FORM

Enemy Coast	Height	Time	Latitude and Longitude	No. of A/c on Tube
Time base used				

2.
At a position between enemy coast and target.

Position	Height	Time	Latitude and Longitude	No. of A/c on Tube
Time base used				

3.
At a position between target and enemy coast.

Position	Height	Time	Latitude and Longitude	No. of A/c on Tube
Time base used				

4.
Maximum range on tube at which aircraft could be detected ... yards.

5.
Minimum range on tube at which aircraft could be detected ... yards.

6.
Number of aircraft located on tube which approached within 600 yards ......

7. Incident Report

Range and position of any visuals obtained of enemy aircraft by the air gunner before the Wireless Operator was warned by the Tube.

Range	Position	Time	

8.
Range and position of visuals of enemy aircraft reported by the Air Gunner after the Wireless Operator was warned by the Tube.

Journey to the Target

Range	Position	Time

At Target

Range	Position	Time

Journey from Target

Range	Position	Time

To be completed on return

Date: Target: Squadron and Letter:

Form No. 6

To: O.R.S., BOMBER COMMAND

VISUAL MONICA RETURN

Date: Target Squadron:

A/c Letters	S ... Serviceable U/S ... Unserviceable M ... Missing	No. of a/c seen on Visual Monica within 1,000 yards while over enemy territory	Incident Report		General Remarks
			Details of suspicious plots on Visual Monica. Action taken if differing from No.1 Group Tactical Instruction. State if confirmed visually, and whether en route or in Target Area	Details of A/c seen without previous warning on Visual Monica. Give range and direction or approach, and whether en route or in Target Area	

APPENDIX No. 3

Form No. 7

<u>'FISHPOND' REPORT</u>

Squadron: Date:

Aircraft Letter: W/Op/AG:

Position A - 30 mins before target.

Position B - 30 mins after target.

Position A: .... Time A. .... Height A: ....

Position B: .... Time B: .... Height B: ....

Number of Responses (a) ....

(refer letter PFF/S/3513/RADAR dated 19. 10. 43) (b) ....

(c) ....

Short Narrative by W/Op/AG
(covering results generally and use of equipment

....

....

....

....

APPENDIX No. 3

Form No. 8

'FISHPOND' REPORT (ISSUE II)

To: H.Q. Bomber Command (Radar Section)

Date: Target: Squadron:

A/c Letter	DIFFICULTIES State whether due to :- (a) H2S u/s or faulty. (b) Only Fishpond u/s or faulty. (c) Manipulation of H2S or Fishpond. (d) Pre-setting of controls before take-off.	No. of A/c seen on screen between 1 and 2 miles at enemy coast		USE (a) Details of suspicious plots on Fishpond. Action taken and if confirmed visually give time and position. (b) Details of E/A seen without previous warning. Give range and direction of approach, particularly whether above or below. Give time and position. (c) General remarks.
		Outward	Homeward	

APPENDIX No. 3

APPENDIX No. 3

Form No. 9

A.G.L.(T) PROFORMA

Date: Target: Squadron: Letter:

Captain: W/Op: R/G:

Failure of equipment or difficulties in manipulation of A.G.L.(T) Fishpond, GGS, Type 'Z' etc.

Time	Equipment	Difficulty

2. Use of A.G.L.(T) and Type 'Z'

A.G.L.(T) Contacts. Maximum Range ______________ Minimum Range ______________
Number of aircraft picked up by A.G.L.(T) ______________
Maximum number of aircraft within range at any one time,
en route ______________ in the target area ______________
How many times were combat manoeuvres taken on A.G.L.(T) indications

____

Give details:

What was the shortest range at which any aircraft was identified friendly ______________
Number of contacts not identified by Type 'Z' ______________
Give brief details with ranges.

3. Use of Fishpond

How much use was made of equipment ? (e.g. in giving warning and keeping watch for other approaches when gunner was holding suspects).

Approx. No. of VI contacts seen first on Fishpond.

Form No. 10

Date:
Squadron No.
Target:

A.G.L.(T) OPERATIONAL REPORT

To: H.Q. Bomber Command (Radar Branch)

Total No. Sorties:
Abortive (T or U/t):
Missing (T or U/t):

A/c Letter	T or U/t	Faults		Reason for Unserviceability	No. of Contacts	No. of Contacts Identified by Type 'Z'	Contacts not Identified by Type 'Z'		Fishpond Contacts before A.G.L.(T)	Action taken
		A.G.L.(T)	Type 'Z'				Range	Reason		Ranges, Combat Manoeuvres, opening fire, etc. State if fire opened on Presentation

APPENDIX No. 3

APPENDIX No. 4

HOLLERITH MACHINERY

Hollerith Card

1. These are rectangular pieces of cardboard with one corner removed, being of three different sizes - 38, 45 and 80 column. All can be punched out in any of 12 positions vertically and this can be repeated in any column. The 80 column card, approximately $7\frac{3}{8}$" x $3\frac{1}{4}$", was used for O.R.S. work.

Punch

2. This machine consists essentially of a carriage, punch keys and punch knives, one for each position, and operates on the typewriter system. On a card being fed into the machine and a punch key depressed a corresponding rectangular hole is punched out in the appropriate column. As the key is released the carriage moves over so that the next column is immediately under the punch knives. There are two more keys on the machine, one a space key which spaces without punching and the other, the release key, allows the carriage to run to its full extent. By holding down the space key the carriage is stopped from moving and thus overpunching can be produced. Two keys may not be depressed at the same time, except in the case of the X and Y (or 11 and 12) keys, either of which may be depressed simultaneously with one of the 0-9 keys (this is to facilitate alphabet punching - see Appendix 5, Form No. 2).

Verifier

3. Mechanical: A mechanical verifier has a similar appearance to a punch, the only difference being that instead of sharp knives it has blunt blades. The verifier operator has both the cards and documents in the same order as they were punched. Each card is fed into the machine and the operator strikes the keys corresponding to the information on the document. Providing the punch blade finds a corresponding hole in the card the machine will space, but if no such hole exists the machine ceases to space. In this case, however, the blade does not pierce the card. The operator then ensures that the card and the document do in fact disagree before destroying the card. The defect of this machine is that it is not possible to check double punching accurately. As two keys cannot be depressed simultaneously, the space key must be held down whilst each hole is checked individually. It is possible at slow speeds to feel

/whether

whether the two holes are punched but at rapid speeds no check is possible as, on releasing the space key after verifying the column, the card will be spaced automatically.

4. Electrical: The operators procedure is exactly the same as that for the mechanical verifier. Instead of punch blades, brushes, one for each hole, make electrical contact with a brass roller and the card is passed between the brushes and the roller. If a hole is sensed, i.e. the brush passes through the hole, one side of a relay is energised. Providing the other side of the relay is simultaneously energised by the depression of the key, the card is allowed to space, but if only one side of the relay is energised, which happens if the key depressed does not correspond with the hole sensed, the machine does not space. When checking double punching, all the keys corresponding to the holes in the card must be depressed. The original type electrical verifier, however, passed a card providing that at least all the keys corresponding to holes punched were depressed. Thus, although this machine was more accurate than a mechanical verifier, 100 per cent accuracy could not be guaranteed on double punched columns. As the work done by O.R.S. involved considerable quantities of double punching the British Tabulating Machine Co. agreed to make a special machine incorporating new features whereby only the depression of the corresponding keys to holes punched would cause the machine to space.

Punch Room Organisation

5. Information about Punch Room organisation is contained at Encl. 14A on BC/52183/ORS., Vol.I and full details concerning normal punching speeds which depend on the number of columns punched are given therein. It was not possible, however, in O.R.S. work to maintain a speed greater than a half to three quarters of those given. Verifying is slightly faster than punching.

Counter/Sorter

6. The counter/sorter is designed for the purpose of counting the holes punched on a given column of the card, and also registering the number of cards not punched in the column. It will simultaneously sort the cards into one of thirteen pockets, twelve of which correspond to the twelve positions of punching and the thirteenth to the cards not punched on the column.

7. The counting mechanism is equipped with fifteen adding counters of five digit capacity each of which is only capable of adding unity for each punching in the appropriate position. 12 counters correspond to the 12 punching positions

/of

of the cards, 1 is for unpunched cards i.e. rejects, 1 counter is for subtotals and the remaining 1 is capable of accumulating the grand total.

8. A selecting device enables all cards punched with any individual hole to be sorted out whilst the remainder are passed into the reject pocket.

9. A card being sorted on an overpunched column is put into the pocket corresponding to the first hole sensed but it sets up a figure 1 in each of the counters corresponding to the holes punched.

10. The rate of feed is 360-400 cards per minute whether sorting or counting, which may be performed separately or simultaneously.

Tabulator

11. There are many different types of this machine with varying functions. A brief description, however, of the Senior Rolling Total Tabulator which was the particular machine used is given below.

12. The tabulator has two main functions - Listing and Tabulating. In listing, each card is read and the information obtained (Alphabetical as well as numerical) is printed by means of print banks. In tabulating, totals which have accumulated in counters from information on the card are printed when required.

13. Before being passed through this machine, the cards have usually been sorted into groups in some numerical sequence. The tabulator can be made to perform various functions whenever the group changes and it is thus possible to obtain totals at the end of each group. It is possible before printing, to transfer totals positively or negatively from one counter to another and after printing to zeroise them. The Tabulator can distinguish three types of change, Major, Intermediate and Minor; it is not necessary to perform the same functions at all three types although at each change of the same type the same functions will always be performed.

14. It is possible to put information from the card onto one of a number of counters or print banks according to some designation on the cards, and negative totals can be printed in their complementary form, if required.

15. Three pluggable boards are used to set up the machine for any particular purpose and plugs providing electrical paths are joined from one socket to another on the board and thus considerable flexibility is provided.

16. The speeds of operation vary according to the type of machine and work but a rough average is given by 80 cards per minute listing and 150 cards per minute tabulating.

/Reproducer

Reproducer

17. The reproducer has two feeds and is capable of copying the information punched on a card in one feed onto the corresponding card in the other. A pluggable board affords flexibility and it is not necessary to copy the information given on a particular column onto the same column on the corresponding card. It is possible, therefore, to reduplicate a pack of cards identically or, alternatively, in a form in which the columns are interchanged. The machine, which operates at a speed of about 100 cards per minute, contains a self checking system whereby the information on the old cards is compared with that on the new ones, the machine ceasing to feed if disagreement is found.

18. It is also possible by using one feed of this machine to copy back information from one card to the following card (Gang-punching). Constant information on a series of cards can thus be mechanically produced.

19. Two additional features are present on this machine - Master Gang-punching and Summary Punching. Before using the Master Gang-punch technique, a series of Master cards, bearing information which is to be gang-punched onto a group of cards, are sorted in front of the groups of detail cards. The whole file of cards is passed through the Reproducer and the information is copied from each master card onto the following group of detail cards. For Summary punching the machine is connected to a Tabulator and at a Minor, Intermediate or Major change, the totals accumulated in the counters can be punched onto cards standing in the Reproducer.

Collator

20. The sorter is only capable of putting cards into sequence and, if it is required to merge together two packs of cards by means of the sorter, the same time is spent whether or not the two separate packs were already in the required sequence. The collator, however, has been designed to deal with this eventuality and is capable of merging together two files of cards both of which are in the same sequence (on not more than 16 columns).

21. After two groups of cards have been sorted, the machine can arrange them in any of the possible ways of associating two sequences of numbers. Many variations of this are possible and, for example, one or more cards in one file may correspond to a particular card in the other file and a card in one group may not have a corresponding card in the other. Two series of cards after

/collating

collating may be arranged into four groups as follows:-

(a) Cards from one file corresponding to those in the other.

(b) Cards from the other file corresponding to those in the first file.

(c) Cards from the first file without corresponding cards in the other file.

(d) Cards from the other file not corresponding to those in the first file.

Items (a) and (b) may be combined to give the corresponding cards from both sections merged into one pack.

22. Operations reverse to collating may also be performed and a file of cards may be separated into two components. Separation is generally brought about by extracting from a file of cards all those corresponding to specially prepared master set or all those corresponding to a particular card. In either case the master set or a pilot card will be presented in the other feed of the machine. The machine is only capable of reading numerical data and cannot distinguish X, Y or O. punching but it is capable of checking that the cards in one feed are in ascending numerical sequence, ceasing to feed if this is not so.

23. Both feeds accept cards at the rate of 12,000 per hour; thus the output varies between 12 and 24,000 cards per hour dependant upon the frequency with which both feeds work simultaneously.

24. The machine is provided with a pluggable board by means of which it is possible to perform the many operations.

Multiplier

25. The machine is available for both decimal and sterling work. It obtains numerical data from two 'fields' (i.e. sections) on the card, up to 8 digits each, multiplies the two together and punches the answer on the same card. At the same time it will accumulate in a counter the totals of products on each card. With a crossfooting device, in addition to multiplication, the machine will add onto the product, one or two numbers obtained from other fields on the card. If an additional crossfooting device is also fitted, the scope of the calculations is further enlarged.

26. With this machine a master card technique similar to that used in gang punching with a Reproducer may also be used. The machine will punch on each detail card the product of a number already on it and a constant number taken from a Master card. When a new master card appears the chain is broken and the process is repeated with a new constant multiplier.

27. It is possible to correct any decimal figure to the nearest whole number either, as each card is punched, or, if using the master card tecnique, at the end of a particular group. A pluggable board is incorporated to give flexibility in obtaining the multiplier and multiplicand, in punching the product, and in determining the particular type of calculation to be performed. The speed of output varies according to the type of calculation and the number of digits involved, but a rough average is 1,000 cards per hour.

Interpreter

28. By means of this machine it is possible to print on the top of the card information punched on it; some specially adapted machines being capable of printing alphabetical information. Cards are normally interpreted when used for reference purposes or when it is required to extract particular cards by hand from a file. The rate of operation is 80 cards per minute, approximately.

APPENDIX No. 5

METHOD OF CODING FOR VARIOUS CARDS PRODUCED BY THE HOLLERITH SECTION

Form

1 - A Raid Report proforma, used for operations on nights subsequent to 18/19 November 1943.

2 - Method of coding cards for Raid Reports in the period 15/16 March 1944, to 29/30 April 1944. (Card No. 1).

3 - A Speciment Raid Report, coded on the system given in Form No. 2.

4 - Raid Report card for the period 1/2 May 1944 to 13/14 August 1944 (Card No. 2).

5 - Method of coding Raid Report card in the period 14/15 August 1944 to 30/31 October 1944. (Card No. 3).

6 - Raid Report card for 1/2 November 1944 to 14/15 March 1945. (Card No.4).

7 - The Raid Report card used for operations subsequent to 15/16 March 1945. (Card No. 5).

8 - Method of coding the card for aircraft intercepted by Enemy Aircraft.

9 - Coding for card punched for Damaged Aircraft.

10 - Card punched from Photographic Interpretation Plottings.

11 - Master Code for reports from returned Evaders.

12 - Master Code and type of cards originally punched for reports from returned Prisoners of War.

13 - Method of obtaining final cards for reports from returned Prisoners of War.

14 - Specimen List and Tabulation produced for analyses into the efficacy of each special equipment.

FORMS 1, 2, 3, 4, 5, 6 and 7, RELATING TO THE CODING OF RAID REPORT CARDS (NOS. 1 to 5)

FORM No. 1

RAID REPORT PROFORMA, USED ON OPERATIONS SUBSEQUENT TO 18/19 NOVEMBER 1943

Section 'A'.

- ∅ Group
- ∅ Date
- ∅ Bomb load and fusing (incl. special flare loads)
- ∅ Special equipment
- ∅ Target and Wave
- Navigators watch error
- ∅ Aircraft Squadron and letter
- Station and Raid Report Number
- ∅ Aircraft Type and Mark
- ∅ Aircraft Serial Number
- Captains Name. (∅ His Experience)
- ∅ Crews Function

Section 'B'. Immediate Reports.

Section 'C'.

∅ 1. Target attacked

∅ 2. Weather over target at time of bombing

∅ 3. How did you identify the target area

∅ 4. Time of attack, height, heading, indicated airspeed

∅ 5. Load dropped in target area (Pathfinder aircraft only)

∅ 6. What was in bombsight

∅ 7. If bombsight not used, how did you bomb

8. Bomb Aimer's description of the target area

9. If any bombs or flares were jettisoned, state place, time, height and reason
If any were brought back, give details and reason

∅ 10. Give place and time where route or warning markers were seen or dropped and remarks as to effectiveness

∅ 11. (A) What if any of the special equipment mentioned above was unserviceable or (B) was not used

12. If a defect affected the result of the mission state which equipment or component failed

∅ 13. Was the aircraft damaged by fighters, flak or other causes, Give brief particulars as to place, time and height

14. If you knowingly deviated from the ordered route, state the route taken and give the reason for the deviation

∅ 15. Describe the effects of any adverse weather encountered, ice etc.

∅ 16. Pilot's personal report

17. Initials of interrogating officer. Time of origin

Note:- Items marked ∅ were coded on the original card.

APPENDIX No. 5

FORM No. 2

RAID REPORT CARD No. 1. (15/16 MARCH 1944 TO 29/30 APRIL 1944)

Method of Coding

SECTION 'A'.

Col. No.	Title	Coding
22	Group	Y. 91 Group. X. 92 Group. 0. 93 Group. 9. 100 Group.
23 to 25	Day and month	Y. December. X. November. 0. October. 1 to 9 January to September.
26	Bomb Load	Y. High Explosive only. X. Incendiaries only. 0. Special. 1. 1,000 lb. 2. 2,000 lb. 3. 30 lbs. incendiary. 4. 4,000 lb. 5. 500 lbs. 6. 4 lbs. incendiary. 7. 'J' type bombs. 8. 8,000 lb. 9. 12,000 lb.
27	Special Equipment (1st Column)	0. Aural Monica 1. Visual Monica. 2. Fishpond. 4. Serrate. 5. Oboe Mk. I. 6. Oboe Mk. II.
28	Special Equipment (2nd Column)	0. Boozer Mk. I 1. Boozer Mk. III. 4. AI. 6. GH.
29	Special Equipment (3rd Column)	6. H2S. 7. H2X.
30	Special Equipment (4th Column)	0. Mandrel. 1. ABC. 4. Modified Rudders. 5. GPI. 6. API. 7. Under Gun/Manned.+) 8. Nitrogen Tank filled.+) Introduced 2. Carpet.+) later. 9. None of above.+)

Note:- Items starred thus + were introduced later, as required.

FORM No. 2 (Page 2)

Col. No.	Title	Coding
31 to 33	Target	As per Target Code Book.
34	Wave	0. Supporter.+
35 to 37	Squadron	
38	Aircraft Letter:-	

English 2 - zone method.

		N.	Y0
A.	X	O.	0.
B.	X0	P.	Y1
C.	X1	Q.	Y2
D.	X2	R.	Y3
E.	X3	S.	8
F.	X4	T.	Y4
G.	6	U.	Y5
H.	X5	V.	Y6
I.	1	W.	Y7
J.	X6	X.	Y8
K.	X7	Y.	Y9
L.	X8	Z.	Y
M.	X9		

American 3 - zone method.

A.	Y1	J.	X1	S.	02
B.	Y2	K.	X2	T.	03
C.	Y3	L.	X3	U.	04
D.	Y4	M.	X4	V.	05
E.	Y5	N.	X5	W.	06
F.	Y6	O.	X6	X.	07
G.	Y7	P.	X7	Y.	08
H.	Y8	Q.	X8	Z.	09
I.	Y9	R.	X9		

The American 3 - zone method was not used by O.R.S., but cards for the period 14/15-8-44 to 30/31-1-45 have the American equivalent of the Aircraft Letter gang-punched on Column 1.

Col. No.	Title	Coding
39	Suffix to Letter	0. LK; NZ. 2. MH; MZ/JN; A4A. (For aircraft letters prefixed by these letters.) 2. Barred Letters
40	Aircraft Type	0. Stirling. 1. Lancaster. 2. Halifax. 3. Wellington. 4. Mosquito. 5. Whitley. 6. Beaufighter.
41	Aircraft Mark	0. Mark 20. 6. Mark 16.
42 to 47	Aircraft Serial Number	
48 and 49	Pilot - Experience	Y. 3rd or more Tour X. 2nd Tour (Col. 49 only.)
50	Function	0. Main Force. 1. Routemarker. 2. Primary Blind Marker. 3. Secondary Blind Marker. 4. Special Blind Marker. 5. Visual Marker. 6. Primary Backer-up. 7. Secondary Backer-up. 8. Supporter. 9. Other.

Note:- Item starred thus + was introduced later, when required.

APPENDIX No. 5

FORM No. 2 (Page 3)

SECTION 'C'.

Col. No.	Title	Coding
51	Question 1. - Result of Mission	0. Missing. 1. Attacked Primary. 2. Attacked alternative. 3. Abortive, over enemy territoty 4. Abortive, NOT over enemy territory. 5. Unknown. 6. Jettisoned in Target Area.+ 8. More than one target attacked.+ (Target No. always punched - 0399). 9. Aircraft crashed in Allied occupied territory.+
52	Question 2. - Cloud (10ths) in Target Area.	
53	Question 3. - Identification of target	Y. Blindly (H2S etc.). X. Glow. 0. Target indicator, other. 1. Target indicator yellow. 2. Target indicator red. 3. Target indicator green. 4. Release point flares. 5. Hooded flares. 6. White flares. 7. Fires. 8. Visually. 9. Other.
54 to 65	Question 4. - Time, height, heading and indicated air speed	Y. Rectified air speed. X. Knots.
66	Question 5. - Load dropped in Target Area (Coded for Pathfinders only).	Y. Delay Target indicator. X. Long burning Target indicator. 0. None. 1. Target indicator yellow. 2. Target indicator red. 3. Target indicator green. 4. Release point flares. 5. Hooded flares. 6. White flares. 7. Ruby Spot. 8. Multiflash. 9. Other.
67	Question 6. - Bombed on	Coding as for para. 3 - Identification of Target.
68	Question 10. - Route Markers	Route markers dropped:- Y. Position 1. X. Position 2. 0. Position 3. 1. Position 4. Route markers NOT dropped:- 2. Position 1. 3. Position 2. 4. Position 3. 5. Position 4. Route markers seen:- 6. Position 1. 7. Position 2. 8. Position 3. 9. Position 4.

Note:- Items marked thus+ were introduced later, as required.

FORM No. 2 (Page 4)

Col. No.	Title	Coding
69 to 72	Question 11(a). - Special Equipment Unserviceable	Coding as for Special Equipment in Section 'A'.
73 to 76	Question 11(b). - Special Equipment not used	Coding as for Special Equipment in Section 'A'.
77	Question 13. - Damage	Y. Engine fires.+ X. Other fires.+ 0. Damaged by flak. 1. Damaged by fighter. 3. Damaged by Collision. 4. Hit by incendiary bombs. 5. Damaged at take-off. 6. Damaged in landing. 7. Crashed. 8. Ditched in sea. 9. Other.
78	Question 15. - Weather	0. Icing encountered. 1. Rime ice. 2. Glaze ice. 3. Pitot Head iced. 4. Crashed due to ice.
79	Question 16. - Seen in Target Area	Y. Decoy Target indicators. X. Decoy flares. 0. Decoy lights or fires. 1. Cascading Target indicator yellow. 2. Cascading Target indicator red. 3. Cascading Target indicator green. 4. Night fighter flares. 5. Haze. 6. Smoke screen. 7. Fires. 8. Explosion. 9. Other.
80	Causes of abortive sorties	1. Weather. 2. Icing. 3. Technical defect. 4. Enemy action. 5. Illness. 6. Recall. 7. Navigational error. 8. Not classified. 9. Reserve aircraft, not required.+

Note:- Items marked thus + were introduced later, as required.

APPENDIX No. 5

FORM No. 3

SPECIMEN CODED RAID REPORT

Section 'A'

6 Group	649/Y
4/5 December, 1943	Holme 459
5 x 2000 lb.	
6 x 90 x 4 lb. inc.	Lancaster III
1 x 90 x 4 lb. 'X' inc.	DV 978
MONICA I, BOOZER I, MANDREL	P/O Prune (18)
BERLIN 8	

Section 'B' Nil

Section 'C'

1. Primary
2. 8/10 tops 5000 ft.
3. Red and green T.I.s
4. 0405, 21,000 ft., 359 Mag, 165 I.A.S.
5. Whole load
6. MPI of green T.IS.
8. Huge explosion at 0409
10. P seen at 5102N,0932E at 0302 hrs. effective
    Q " " 5223N,0945E at 0345 hrs. effective
11A Monica B. Boozer
12. P/O had to be feathered
13. Hit by flak in the target area 0201
15. Icing in clouds
17. JEF 0907

FORM No. 4

RAID REPORT CARD No. 2. (1/2 MAY 1944 to 13/14 AUGUST 1944)

SECTION 'A'

Col. No.	Title
39	Group
40 to 42	Date
43	Bomb Load
44 to 47	Special Equipment
48 to 51	Target
52	Wave
53 to 57	Squadron & Letter
58	Aircraft Type
59	Aircraft Mark
60 to 65	Aircraft Serial Number
66 to 67	Pilot - Experience
68	Function

SECTION 'C'

69	Result of Mission
70	Cloud (10ths) in Target Area
71 to 76	Time; Height
77	Bombed on
78	Damage
79	Weather
80	Causes of Abortive Sorties

Note:- Coding for this card is identical to the original coding - Card 1.

FORM No. 5

APPENDIX No. 5

RAID REPORT CARD No. 3. (14/15 AUGUST 1944 to 30/31 OCTOBER 1944)

Method of Coding

N.B. Although cards for the period 14/15 August 1944 to 30/31 October 1944 were originally punched in this form, they were subsequently reproduced in the form of Card No. 5. The cards which at present exist for this period, are in the form of Card No. 5 and also have the American equivalent of the Aircraft Letter punched on Column 1.

SECTION 'A'

Col. No.	Title	Coding
37	Group	
38 to 40	Date	
41	Bomb Load	
42	Special Equipment (1st Column)	1. Monica III. 3. Monica V. 4. Fishpond. 5. Loran. 6. Loran and Fishpond.
43	Special Equipment (2nd Column)	1. Boozer. 2. Village Inn (A.G.L.(T)).
44	Special Equipment (3rd Column)	1. H2S II. 2. H2S III. 3. GH. 4. Oboe I. 5. Oboe II. 6. Oboe III. 8. H2S II and GH.
45	Special Equipment (4th Column)	1. Mandrel. 4. ABC. 5. Carpet.
46	Special Equipment (5th Column)	1. Under-Gun/Manned.
47	Special Equipment (6th Column)	1. Nitrogen Tank unfilled. 2. Nitrogen Tank filled. 9. Unequipped with any of above.
48 to 51	Target	
52	Wave	
53 to 57	Squadron and Letter	
58	Aircraft Type	
59	Aircraft Mark	
60 to 65	Aircraft Serial No.	
66 to 67	Pilot - Experience	
68	Function	

Note:- Coding for information, other than Special Equipment, remained the same as that given for the original card - No. 1.

APPENDIX No. 5

FORM No. 5 (Page 2)

SECTION 'C'

Col. No.	Title
69	Question 1. - Result of Mission
70	Question 2. - Cloud (10ths) in Target Area
71 to 76	Question 4. - Time, height, heading and Indicated Air Speed
77	Question 6. - Bombed on
78	Question 13. - Damage
79	Question 15. - Weather
80	Causes of Abortive Sorties

Note:- Coding for the above information remained the same as that given for the original card - No. 1.

FORM No. 6

APPENDIX No. 5

RAID REPORT CARD No. 4. (1/2 NOVEMBER 1944 to 14/15 MARCH 1945)

Method of Coding

N.B. Although cards for the period 1/2 November 1944 to 30/31 January 1945 were originally produced in this form, they were subsequently reproduced in the form of Card No. 5. Cards which at present exist for this period are in the form of Card No. 5 and have the American equivalent of the Aircraft Letter punched on Column 1.

SECTION 'A'

Col. No.	Title	Coding
36	Group	
37 to 39	Date	
40	Bomb Load	
41	Special Equipment (1st Column)	4. Fishpond. 5. Loran. 6. Loran and Fishpond.
42	Special Equipment (2nd Column)	1. Boozer. 2. A.G.L.(T).
43	Special Equipment (3rd Column)	1. H2S II. 2. H2S III. 3. GH. 4. Oboe I. 5. Oboe II. 6. Oboe III. 7. H2S II (used for fixes only). 8. H2S and GH. 9. H2S III (used for fixes only).
44	Special Equipment (4th Column)	4. ABC. 5. Carpet.
45	Special Equipment (5th Column)	1. Under-Gun/Manned.
46	Special Equipment	1. Nitrogen Tank unfilled. 2. Nitrogen Tank filled. 9. Unequipped with any of the above.

Method of Coding for H2S and Fishpond

Radiation silence (for whole of operation).	Neither H2S nor Fishpond coded. Aircraft considered as unequipped.
Radiation silence (H2S used for fixes only).	Fishpond not coded. H2S II coded as 7 in 3rd Column. H2S III coded as 9 in 3rd Column.
H2S unrestricted for whole or part of operation over enemy territory	Fishpond and H2S coded normally.

Note:- Coding for sections other than those detailed above, remained the same as that given for the original card No. 1.

APPENDIX No. 5

FORM No. 6 (Page 2)

Card No. 4 (continued).

Col. No.	Title	Coding
47 to 50	Target	
51	Wave	
52 to 56	Squadron and Letter	
57	Aircraft Type	
58	Aircraft Mark	
59 to 64	Aircraft Serial Number	
65 to 66	Pilot - Experience	
67	Function	Y. Window Opener. X. Controller. Master Bomber. Deputy Master Bomber. 0. Main Force. 1. Blind Marker Illuminator. 2. Oboe Marker. 3. Secondary Blind Marker. 4. Blind Illuminator. 5. Visual Marker. 6. Backer-Up. 7. Primary Blind Marker. 8. Supporter. 9. Photo Recce. Late Bomber. Routemarker. Wind Finder. Spoof Marker. X4. Visual Illuminator.

SECTION 'C'

Col. No.	Title		Coding
68	Question 1.	Result of Mission	
69	Question 2.	Cloud (10ths) in Target Area	
70 to 73	Question 4.	Time	
74 to 75	Question 4.	Height	
76 to 77	Question 6.	Bombed on (1st Column)	Y. Information given not definite. X. Dead-reckoning run. 0. GPI. 1. Target Indicator other. 2. Target Indicator red. 3. Target Indicator green. 4. Release point flares. 5. H2S or Oboe. 6. Gee; GH; Loran. 7. Smoke or fires. 8. Visually

FORM No. 6 (Page 3)

Card No. 4 (continued).

Col. No.	Title	Coding
76 to 77	Question 6. Bombed on (2nd Column)	Y. More than one run made. Coded information applies to 1st only. X. Dead-reckoning run. 0. GPI. 1. Target Indicator other. 2. Target Indicator red. 3. Target Indicator green. 4. Release point flares. 5. H2S or Oboe. 6. Gee; GH; Loran. 7. Smoke or fires. 8. Visually.

Information coded for Aircraft bombing only one of the above was coded and punched in the first column.
An Aircraft which bombed two of the above was coded and punched in both columns; the major method of bombing appearing in the first column.
Aircraft which bombed on more than two of the above were counted as bombing on the two major categories only.

78	Question 13. Damage	
79	Question 15. Weather	
80	Causes of Abortive Sorties.	

Note:- Coding for sections other than those detailed above, remained the same as that given for the original card in No. 1.

APPENDIX No. 5

FORM No. 7

RAID REPORT CARD No. 5 (15/16 MARCH 1945 onwards)

Method of Coding

N.B. Cards for the period 14/15 August 1944 to 30/31 January 1945 were subsequently reproduced in this form.

SECTION 'A'

Col. No.	Title	Coding
33	Group	
34 to 35	Date) Month)	
37	Bomb Load	
38	Special Equipment (1st Column)	1. Fishpond. 2. Monica I. 3. Monica III. 4. Monica V. 5. Oboe I. 6. Oboe II. 7. Oboe III.
39	Special Equipment (2nd Column)	1. Boozer. 2. A.G.L.(T). 3. Gyro Gun Sight. 9. Boozer I.
40	Special Equipment (3rd Column)	1. H2S II. 2. H2S III. 7. H2S II. (for fixes only). 8. H2S III. (for fixes only). 9. Under Gun/Manned.
41	Special Equipment (4th Column)	1. Carpet Range 1. 2. Carpet Range 2. 5. ABC. 6. Modified Flame Dampers. (1 Group only). 9. Carpet.
42	Special Equipment (5th Column)	1. Paddle Blades.
43	Special Equipment (6th Column)	1. Nitrogen Tank filled.
44	Special Equipment (7th Column)	1. Loran. 2. GH. 9. Modified Rudders.
45	Special Equipment (8th Column)	1. Glen Martin Turret. 9. Mandrel.
46	Special Equipment (9th Column)	1. Rose Bros. Turret. (1 Group only). 2. Frazer Nash '82' Turret. 3. Boulton Paul (D) Turret. 9. Unequipped with any of the above.

Note:- Coding for information, other than Special Equipment, remained the same as that given for the original card No. 1.

FORM No. 7 (Page 2)

APPENDIX No. 5

Col. No.	Title
47 to 50	Target
51	Wave
52 to 54	Squadron
55 to 56	Aircraft Letter
57	Aircraft Type
58	Aircraft Mark
59 to 64	Aircraft Serial No.
65 to 66	Pilot - Experience
67	Function

SECTION 'C'

68	Question 1.	Result of Mission
69	Question 2.	Cloud (10ths) in Target Area
70 to 73	Question 4.	Time
74 to 75	Question 4.	Height
76 to 77	Question 6.	Bombed on
78	Question 13	Damage
79	Question 15	Weather
80	Causes of Abortive Sorties	

Note :- Coding for information, other than Special Equipment, remained the same as that given for the original card in No. 1.

FORMS 8, 9 and 10, SHOWING METHOD OF CODING INTERCEPTION, DAMAGE AND PHOTOGRAPHIC CARDS

APPENDIX No. 5

FORM No. 8

INTERCEPTION CARD

Method of Coding

Col. No.	Title	Coding	
55	Number of Attacks		
56	Number of Combats		
57	Card Type		
58 to 60	Date		
61 to 64	Target		
69 to 71	Squadron		
72 to 73	Aircraft Letter		
74 to 80	Description of Incident:-		
74	Position on route	Y. Outbound X. Homebound 0. In Target Area 1. Position not given	For 1st Attack
		2. Outbound 3. Homebound 4. In Target Area 5. Position not given	For 2nd Attack
		6. Outbound 7. Homebound 8. In Target Area 9. Position not given	For 3rd Attack
75	Direction of Attack (1st Column)	Y. Up X. Down 0. Level 1. Not stated	in 1st Attack
		2. Up 3. Down 4. Level 5. Not stated	in 2nd Attack
		6. Up 7. Down 8. Level 9. Not stated	in 3rd Attack
76	Direction of Attack (2nd Column)	Y. Astern or quarters X. Beam 0. Bow or ahead 1. Not stated	in 1st Attack
		2. Astern or quarters 3. Beam 4. Bow or ahead 5. Not stated	in 2nd Attack
		6. Astern or quarters 7. Beam 8. Bow or ahead 9. Not stated	in 3rd Attack

FORM No. 8 (Page 2)

Col. No.	Title	Coding	
77	Type of Enemy aircraft	Y. Single-engined aircraft X. Twin-engined aircraft 0. Four-engined aircraft 1. Unidentified aircraft	in 1st Attack
		2. Single-engined aircraft 3. Twin-engined aircraft 4. Four-engined aircraft 5. Unidentified aircraft	in 2nd Attack
		6. Single-engined aircraft 7. Twin-engined aircraft 8. Four-engined aircraft 9. Unidentified aircraft	in 3rd Attack
78	Warning received from:-	Y. Monica III X. Fishpond 0. Boozer 1. Monica V	in 1st Attack
		2. Monica III 3. Fishpond 4. Boozer 5. Monica V	in 2nd Attack
		6. Monica III 7. Fishpond 8. Boozer 9. Monica V	in 3rd Attack
79	Warning NOT received from:-	Y. Monica III X. Fishpond 0. Boozer 1. Monica V	in 1st Attack
		2. Monica III 3. Fishpond 4. Boozer 5. Monica V	in 2nd Attack
		6. Monica III 7. Fishpond 8. Boozer 9. Monica V	in 3rd Attack
80	Not known if warning received from:-	Y. Monica III X. Fishpond 0. Boozer 1. Monica V	in 1st Attack
		2. Monica III 3. Fishpond 4. Boozer 5. Monica V	in 2nd Attack
		6. Monica III 7. Fishpond 8. Boozer 9. Monica V	in 3rd Attack

APPENDIX No. 5

FORM No. 9

DAMAGE CARD

Method of Coding

Col. No.	Title	Coding
55 to 56	Number of strikes	XX. Large, unknown.+
57	Strikes from shell of type:-	X. More than one type of shell. 0. Heavy flak fragment. 1. Heavy flak shell (direct strike). 2. 7.92mm bullet. 3. 13mm shell. 4. 20mm shell. 5. 30mm shell. 6. 40mm shell. 7. 50mm shell. 8. British .303in. bullet. 9. British 0.5in. bullet.) +
58 to 59	Day	
60	Month	
61 to 64	Target	
65	Group	
66	Type of aircraft	
67	Mark of aircraft	
68	Damaged by	0. Flak. 1. Fighter. 3. Collision. 4. Incendiary Bombs. 5. Take-off. 6. Landing. 7. Crashed, otherwise. 8. Ditched in sea. 9. Other.
69 to 71	Squadron	
72 to 73	Aircraft Letter	
74 to 79	Aircraft Serial Number	
80	Category of damage	1. Cat. 'A' 2. Cat. 'AC' 3. Cat. 'B' 4. Cat. 'E'

Note:- Information marked thus + was recorded from 1 October 1944 onwards.

APPENDIX No. 5

FORM No. 10

PHOTOGRAPHIC INFORMATION

Method of Coding

Col. No.	Title	Coding	
56	Year		
57	Card Type		Photo cards punched - 2
58 to 59	Day		
60	Month		
61 to 64	Target		Time punched whenever given on plotting list, otherwise left blank.
65 to 68	Time		
69 to 71	Squadron		
72 to 73	Aircraft Letter		
74 to 75	Miles	Distance of plot from Aiming Point.	
76	Decimals of a mile	Distance of plot from Aiming Point.	
77 to 79	Bearing of plot from Aiming Point.		
	Method of plotting	Y. Plotted by ground detail. X. Plotted by fire tracks. 1. Plotted 0 to 1 mile from Aiming Point. 3. Plotted 1 to 3 miles from Aiming Point. 9. Plotted 3.1 or more miles away from Aiming Point.	

APPENDIX No. 5

FORMS 11, 12 and 13
RELATING TO CARDS FOR REPORTS FROM RETURNED EVADERS AND PRISONERS OF WAR

APPENDIX No. 5

Form No. 11

MASTER CODE FOR RETURNED EVADERS

Col. No.

2-4 Squadron ....
5 Letter ....
6 Type .... A/C No. ....
7 Mark ....
8, 9 Date ....
10, 11 Target ....

Route: Base ....

....

Briefed Time over Target....................... Bomb Load ....

Crew:

* Position Name Rank Experience Fate (give details if known)

** 12 ... Pilot ....

13 ... Nav. ....

14 ... W/Op. ....

15 ... F/Eng. ....

16 ... A/B ....

17 ... M/U/G ....

18 ... R/G ....

19 ... .

* Tick Captain
** For Fate of Crew (Code all that applies)

(Y) Injury due to non-enemy action
(X) Injury due to enemy action
Nothing Evaded
(0) Killed or P/W
(1) Missing
(2) Unhurt
(3) Slight injury in Air
(4) Slight Injury on Ground
(5) Serious injury in Air
(6) Serious injury on Ground
(7) Killed in Air during incident
(8) Killed on Ground during incident
(9) Dead on Ground, details unknown
Nothing Physical Fate Unknown

---

20. Cause of Loss
(12) Falling bombs
(11) Collision
(0) Unknown
(1) Fighter
(2) H.F.
(3) L.F.
(4) Flak (Type unknown)
(5) Flak & Fighter
(6) Flak or Fighter (Not known which)
(7) Unintentional Crash
(8) Engine Failure
(9) Other

Interrogator's Comments

/ 21

Form No. 11 (Page 2)

21. Final Cause of Loss — Interrogator's Comments

(0) Unknown
(1) Fire
(2) Control Failure
(3) Engine Failure
(4) Aircraft unairworthy
(5) Fuel shortage
(6) Explosion in air
(7) Other
(8) Two or above both decisive final causes of loss

22. Route — Interrogator's Comments

(12) Intentional deviation from planned flying schedule
(11) Unintentional deviation from planned flying schedule
(0) Nothing known
(1) Route adhered to
(2) Off route at time of incident
(3) Off planned height at time of incident
(4) Off planned timing at time of incident
(5) On route at time of incident
(6) On planned height at time of incident
(7) On planned timing at time of incident
(8) Planned petrol consumption adhered to
(9) Planned petrol consumption not adhered to

23. Weather (Time of Incident) (Tick all that apply) — Interrogator's Comments

(Y) Atmospheric peculiarities other than icing experienced
(X) Icing experienced
(1) Clear, no cloud
(2) Clear, above low haze or cloud
(3) Clear below high haze or cloud
(4) Up to 5/10 cloud below bomber
(5) 6/10-9/10 cloud below bomber
(6) 10/10 cloud below bomber
(7) 5/10 cloud above bomber
(8) 6/10-9/10 cloud above bomber
(9) 10/10 cloud above bomber

24. Visibility at time of incident (Tick one numbered answer on visibility, one on moon) — Interrogator's Comments

(X) A/C directly illuminated by moon
(0) Visibility not known
(1) Vis. poor
(2) Vis. moderate
(3) Vis. good
(4) Vis. very good
(5) No moon
(6) Moon up but not providing effective illumination
(7) Half moon up
(8) Full or nearly full moon up
(9) State of moon not known

/ 25

APPENDIX No. 5

Form No. 11 (Page 3)

25. Defences encountered at the Time of Incident — Interrogator's Comments (Phenomena, etc.)

(Y) Flak intense
(X) Flak moderate
(0) Not known
(1) None
(2) L.F. no searchlights
(3) H.F. no searchlights
(4) L.F. and searchlights
(5) H.F. and searchlights
(6) L.F. and H.F. no searchlights
(7) L.F. and H.F. and searchlights
(8) Searchlights only

26. INCIDENT — Interrogator's Comments (State nearest inhabited place)

Position on Route

(Y) Orbitting
(X) Dogleg off route
(1) Outbound N.O.E.T.
(2) Outbound O.E.T. more than 30 miles from the target
(3) Outbound O.E.T. less than 30 miles from the target
(4) Target area
(5) Homebound O.E.T. less than 30 miles from the target
(6) Homebound O.E.T. more than 30 miles from the target
(7) Homebound N.O.E.T.
(8) Homebound (Intruder)

27, 28 HEIGHT OF INCIDENT (In thousands of feet)

.... thousand feet

29. Evasive Action immediately before Incident — Interrogator's Comments

(12) Not known
(11) None
(0) Weaving
(1) Corkscrew
(2) Turn
(3) Dive
(4) Diving turn
(5) Climb

Habitual evasive action

(6) Habitual evasive action none
(7) Habitual evasive action weaving
(8) Habitual evasive action banking search
(9) Habitual evasive action irregular changes of course

30. Evasive Action During Incident

(0) Not known
(1) None
(2) Weaving
(3) Corkscrew
(4) Turn
(5) Dive
(6) Diving turn
(7) Climb

31. Silhouette, Searchlights, etc. At time of Incident (Tick all that apply) — Interrogator's Comments

(Y) A/C matt painted
(X) A/C glossy painted
(0) Not known
(1) No silhouette, no searchlights
(2) Illuminated by single searchlight
(3) Coned by searchlights
(4) Silhouette against searchlights on ground
(5) " " burning flares, fires or lights on ground
(6) " " Illuminated cloud
(7) " " light part of sky
(8) " " moon
(9) " " Fighter flares near

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APPENDIX No. 5

Form No. 11 (Page 4)

32. Special Equipment Carried (Tick all that apply) — Interrogator's Comments
(0) Oboe
(1) Monica I
(2) Monica III
(3) Monica V
(4) Boozer
(5) Carpet
(6) Fishpond
(7) H2S
(8) H2X
(9) A.G.L.T.

33. Monica (whichever mark carried) or Fishpond — Interrogator's Comments
(Y) Operator trained
(X) Operator not trained
(0) Nothing known
(1) Switched off
(2) Unserviceable
(3) Gave first warning
(4) Warned later
(5) Gave no warning
(6) Not watched

34. Boozer — Interrogator's Comments
(0) Nothing known
(1) Switched off
(2) Unserviceable
(3) Gave first warning
(4) Gave warning later
(5) Gave no warning

A.G.L.T. — Interrogator's Comments (Range and position at pickup, identification and opening fire)
(X) Damaged by e/a during incident
(0) Nothing known
(1) Unserviceable
(2) Gave first warning
(3) Pickup after Monica or Fishpond
(4) Pickup after visual
(5) Not picked up on A.G.L.T.
(6) Type Z not used
(7) Type Z telescope unserviceable
(8) Ident. hostile on Z
(9) Not identified on Z

35. Other Radar — Interrogator's Comments
(Y) H2S switched on
(X) H2S switched off
(0) Condition of H2S not known
(1) Carpet switched on, jamming
(2) Carpet switched on, sweeping
(3) Carpet switched on, performance unknown
(4) Carpet switched off
(5) Condition of Carpet not known
(6) Window being dropped at start of incident
(7) Window dropped during incident
(8) Window not dropped
(9) Not known if Window dropped

/ 36.

APPENDIX No. 5

Form No. 11 (Page 5)

36. Fighter Type

(Y) Type identified (definite)
(X) " " (doubtful)
(0) Nothing known
(1) No Visual. Not seen on Spec. Equip.
(2) " " Seen on Spec. Equip.
(3) Visual. Not identified
(4) Enemy. Single Engined
(5) " Twin "
(6) " Four "
(7) " Jet. propelled
(8) Friendly type
(9) Other

Interrogator's Comments (State type if possible. If friendly was Z switched on?)

37. Direction of Attack (Tick all that apply)

(Y) Astern
(X) Ahead
(0) Not known
(1) Port
(2) Line
(3) Starboard
(4) Above
(5) Level
(6) Below
(7) Quarter
(8) Beam
(9) Bow

Interrogator's Comments

38. Position of First Fighter

(Y) Fighter seen by Direct illumination
(X) Fighter seen by silhouette
(0) Not known
(1) Rear Turret
(2) Mid Upper Turret
(3) Mid Under Turret
(4) Astrodome
(5) Pilot's Cockpit
(6) Air Bomber's Compartment
(7) Not sighted
(8) Other

Interrogator's Comments

39. Combat

(Y) Surprise Attack
(X) Fighter Destroyed
(0) Nothing known
(1) Bomber did not fire
(2) Bomber fired first, fighter second
(3) Bomber and fighter fired simultaneously
(4) Fighter fired first, bomber second
(5) Both fired, order unknown
(6) Not known if bomber fired, but fighter fired first

Interrogator's Comments

40. Rear Guns and Turret (Tick all that apply)

(Y) Rear guns not manned at time of attack
(X) Turret u/s by e/a before firing
(0) Not known
(1) Guns unserviceable before attack
(2) Turret hydraulics u/s before attack
(3) Turret electrics u/s before attack
(4) Serviceable but not used
(5) Serviceable and used
(6) Guns jammed
(7) Guns damaged by e/a
(8) Hydraulics damaged by e/a
(9) Electrics damaged by e/a

Interrogator's Comments

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41. Mid Upper Guns and Turret (Tick all that apply) — Interrogator's Comments

(Y) M/U Guns not manned at time of attack
(X) Turret u/s by e/a before firing
(0) Not known
(1) Guns unserviceable before attack
(2) Turret hydraulics u/s before attack
(3) Turret electrics u/s before attack
(4) Serviceable but not used
(5) Serviceable and used
(6) Guns jammed
(7) Guns damaged by e/a
(8) Hydraulics damaged by e/a
(9) Electrics damaged by e/a

42. Mid Under Guns and Turret (Tick all that apply) — Interrogator's Comments

(Y) Mid Under guns not manned at time of attack
(X) Turret u/s by e/a before firing
(0) Not known
(1) Guns unserviceable before attack
(2) Turret hydraulics u/s before attack
(3) Turret electrics u/s before attack
(4) Serviceable but not used
(5) Serviceable and used
(6) Guns jammed
(7) Guns damaged by e/a
(8) Hydraulics damaged by e/a
(9) Electrics damaged by e/a

43. Armament used by Fighter — Interrogator's Comments

(Y) Cannon Tracer
(X) M/G tracer
(0) Not known
(1) M.Gs.
(2) M.Gs. and cannon
(3) Cannon
(4) R.Ps.
(5) Upward firing guns

FLAK ONLY

44. Type of Flak (Tick those that apply) — Interrogator's Comments

(Y) Flak believed predicted
(X) Flak believed barrage
(0) Flak believed in plotted concentration
(1) Not known whether H.F. or L.F.
(2) L.F.
(3) L/F and H/F
(4) H/F
(5) One shell hit
(6) Two shells hit
(7) Three shells hit
(8) More shells hit
(9) No. of hits unknown

INCENDIARY OR H.E. BOMBS (Tick all that apply) — Interrogator's Comments

45. (12) Nothing known
(11) One bomb
(0) Many bombs
(1) No. of bombs not known
(2) Bombs ignited on impact
(3) Not known if bombs ignited on impact
(4) Bombs caused fire
(5) Not known if bombs caused fire
(6) Bombs remained on aircraft
(7) H.E. Bombs
(8) Incendiary Bombs
(9) Unopened Incendiary Cluster

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COLLISION (Tick all that apply)

Interrogator's Comments (Give details of light and identity of other a/c if known).

46. (Y) Other aircraft hostile
(X) Other aircraft friendly
(0) Nothing known
(1) Did other aircraft approach from beam ?
(2) " " " " " ahead?
(3) " " " " " astern?
(4) " " " " " above?
(5) " " " " " below?
(6) Other aircraft visible before collision
(7) Other aircraft seen to be destroyed
(8) Avoiding action taken

DAMAGE TO BOMBER

Interrogator's Comments

47. Controls - Ailerons
(Y) Control mechanism hit
(X) Control surface hit
(0) Nothing known
(1) Not hit
(2) Hit but no details known
(3) Controls damaged but still partially effective
(4) Controls damaged and ineffective
(5) Controls effective - not known if hit

48. Controls - Elevators

Interrogator's Comments

(Y) Control mechanism hit
(X) Control surface hit
(0) Nothing known
(1) Not hit
(2) Hit but no details known
(3) Controls damaged but still partially effective
(4) Controls damaged and ineffective
(5) Controls effective, not known if hit

49. Controls - Rudder

Interrogator's Comments

(Y) Control mechanism hit
(X) Control surface hit
(0) Nothing known
(1) Not hit
(2) Hit but no details known
(3) Controls damaged but still partially effective
(4) Controls damaged and ineffective
(5) Controls effective, not known if hit

50. Engines (Tick all that apply)

Interrogator's Comments

(12) Nothing known
(11) No engines damaged
(0) Engine on fire
(1) Coolant system damaged
(2) Control system damaged
(3) Propeller damaged
(4) Other accessories damaged
(5) Engine hit but not on fire
(6) P/O engine damaged
(7) P/I engine damaged
(8) S/I engine damaged
(9) S/O engine damaged

51. Fuel System (Tick all that apply)

Interrogator's Comments

(Y) Nitrogen tanks not filled
(X) Nitrogen filled tanks
(0) Nothing known
(1) Not hit
(2) Tanks hit, fuel lost
(3) Tanks hit, on fire
(4) Tanks hit, exploded
(5) Main fuel pipe hit
(6) Fuel controls hit
(7) Tanks hit known to be empty
(8) Tanks hit known to be partially filled with petrol
(9) Tanks hit known to be completely filled with petrol.

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52. Hydraulics (tick all that apply) — Interrogator's Comments
(0) Nothing known
(1) Not hit
(2) Main hydraulic hit
(3) Landing services (flaps & u/c) hit
(4) Turret hydraulics hit
(5) Emergency hydraulics hit
(6) Other hydraulics hit
(7) Hydraulic fire
(8) Hydraulic fluid lost
(9) Unable to open bomb doors

53. Radio and Electrics (Tick all that apply) — Interrogator's Comments
(0) Nothing known
(1) W/T hit
(2) Intercomm. unserviceable
(3) Intercomm. made u/s during attack
(4) Emergency call light system hit or u/s
(5) Gee hit
(6) H2S or H2X hit
(7) General electric services failed
(8) Bomb fusing and release gear hit
(9) Minor electric services (lamps, etc.) hit

54. Bombs, etc. (tick all that apply) — Interrogator's Comments
(0) Nothing known
(1) Not hit
(2) Bombs on fire
(3) Bombs exploded
(4) Flares on fire
(5) Flares exploded
(6) Ammunition on fire
(7) Ammunition exploded
(8) Photoflash exploded
(9) Bombs not carried at time of incident

55. Oil System (tick all that apply) — Interrogator's Comments
(0) Nothing known
(1) Not hit
(2) Tank hit
(3) Pipes hit
(4) Oil cooler hit
(5) Oil system hit, no details known
(6) Oil fire
(7) Fall in oil pressure observed, followed by seizure
(8) Fall in oil pressure observed, engine feathered before seizure
(9) Fall in oil pressure observed, engine continued running

56. Instruments and other services (tick all that apply) — Interrogator's Comments
(12) Nothing known
(11) Instruments not hit
(0) Navigational instruments hit or u/s
(1) Blind flying instruments hit or u/s
(2) Engineer's instruments hit or u/s
(3) Oxygen system, high pressure damaged
(4) Oxygen system, low pressure damaged
(5) Oxygen bottles exploded
(6) Pneumatic system hit
(7) Vacuum system (pesco pump) hit
(8) George hit or u/s.
(9) Other instruments or services hit

/57.....

57. Airframe and Non-localised Damage (tick all that apply)

Interrogator's Comments (Give all known details)

(Y) Major airframe damage caused by fire or explosion subsequent to initial damage
(X) Airframe damage not covered by (2)-(9)
(0) Nothing known
(1) No damage to airframe
(2) Wing surface damaged
(3) Wing main spar damaged
(4) Large part of wing severed
(5) Tail unit surface damaged
(6) Large part of tail unit severed
(7) Fuselage surface damage, including pilot's and bomb aimer's perspex
(8) Extensive damage to interior of fuselage
(9) Aircraft came to pieces in air

FINAL CAUSES OF LOSS (Including Indirect Causes)

Interrogator's Comments

58. Location of Fires (tick all that apply)
(Y) Fuselage fire
(X) Wing fire
(0) Nothing known
(1) Petrol
(2) Oil
(3) Hydraulic fluid
(4) Pyrotechnic stores
(5) Incendiary bombs
(6) Engines
(7) Electrics and radar
(8) Coolant fluid
(9) WINDOW in fuselage

59. Engine Fire Drill (tick all that apply)

Interrogator's Comments

(Y) Dived in attempt to put out fire
(X) Attempt made to restart engine
(0) Nothing known
(1) Engine feathered
(2) Did not attempt to feather engine
(3) Unable to feather engine
(4) Graviner used
(5) Graviner not used
(6) Fire drill correct
(7) Fire drill incorrect
(8) Fire extinguished
(9) Fire not extinguished

60. Fires - General

Interrogator's Comments

(Y) Fire spread rapidly
(X) Asphyxiating fumes experienced
(0) Nothing known
(1) Engine fire immediately
(2) Engine fire after delay
(3) Other fire immediately
(4) Other fire after delay
(5) Fire originated in engine
(6) Aircraft remained airworthy in spite of fire
(7) Aircraft not airworthy due to fire
(8) Unsuccessful attempt to extinguish non-engine fire
(9) Successful attempt made to extinguish non-engine fire

61. Engine fires and failure - general

Interrogator's Comments

(Y) More than one engine on fire
(X) More than one engine failed
(0) Not known which engines on fire
(1) P/O on fire
(2) P/I on fire
(3) S/I on fire
(4) S/O on fire
(5) Not known which engines failed
(6) P/O Failed
(7) P/I failed
(8) S/I failed
(9) S/O failed

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62. Controls failure — Interrogator's Comments.

Y. Aircraft uncontrollable.
X. Aircraft in limited control.
0. Nothing known.
1. Aircraft straight and level.
2. Aircraft in spin.
3. Aircraft in dive.
4. Aircraft in diving turn.
5. Aircraft climbing.
6. Aircraft in other attitudes (state which).
7. Aircraft lost solely because of control failure.

63. Engine failure. (Tick all that apply) — Interrogator's comments. (Note abnormal engine conditions, temperatures, etc.).

Y. Due to enemy action.
X. Not due to enemy action.
0. Nothing known.
1. Loss of boost.
2. Loss or fluctuations of revs.
3. Loss of oil pressure.
4. Coolant failure.
5. Engine 'ran away'.
6. Propeller fell off.
7. Propeller unfeathered spontaneously.
8. Engine vibrated.
9. Other points (state).

64. Fuel shortage — Interrogator's comments.

X. If aircraft abandoned solely because of F/S.
0. Not known.
1. Due to holing of tanks.
2. Due to holing of pipes.
3. If not (1) or (2), due to overconsumption.
4. If not (1) or (2), due to mismanipulation.
5. If not (1) or (2), due to deviation from planned flying schedule.
6. Due to leak (non-enemy action).

65. Distance between incident and loss (miles). — Interrogator's comments.

1. 25 or less.
2. 26 to 50
3. 51 to 75
4. 76 to 100
5. 101 to 125
6. 126 to 150
7. 151 to 175
8. 176 to 200
9. over 200.

66. Was there any explosion? (Tick all that apply). — Interrogator's comments.

Y. Fire after explosion.
X. Fire before explosion.
0. Not known.
1. In the air before baling out.
2. In the air during baling out.
3. In the air after baling out.
4. On the ground.
5. No explosion.
6. More than one explosion.
7. Explosion caused break-up of aircraft.
8. Explosion broke off wing or part of wing.

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FATE OF CREW | Interrogator's Comments.

67 - 72 Tick the correct number in each category.

Crew killed.
0,1,2,3,4,5,6,7,8.

Crew seriously injured.
0.1.2.3.4.5.6.7.8.

Crew Slightly injured.
0,1,2,3,4,5,6,7,8.

Crew unhurt.
0,1,2,3,4,5,6,7,8.

Crew fate unknown.
0,1,2,3,4,5,6,7,8.

Crew evaded capture.
0,1,2,3,4,5,6,7,8.

73 Action taken by crew. | Interrogator's Comments.

Y. Aircraft known to be completely destroyed or sunk.
X. Aircraft known to have escaped destruction.
1. Baled out.
2. Ditched in sea.
3. Crashed intentionally.
4. Crashed unintentionally.
5. Baled out and ditched in sea.
6. Baled out and crashed intentionally.
7. Baled out and crashed unintentionally.
8. Blown out of aircraft by explosion.
9. None of 1 to 8 (state what happened).

74 Hatches (tick all that apply). | Interrogator's Comments. (Give troubles).

12. Not known.
11. No hatch troubles.
0. Front escape hatch jammed temporarily.
1. Front escape hatch jammed permanently.
2. Rear escape hatch jammed temporarily.
3. Rear escape hatch jammed permanently.
4. Top R.E.H. jammed temporarily.
5. Top R.E.H. jammed permanently.
6. Top M.E.H. jammed temporarily.
7. Top M.E.H. jammed permanently.
8. Pilot's hatch jammed temporarily.
9. Pilot's hatch jammed permanently.

75 General points - Crashes (tick all that apply). | Interrogator's Comments. (Full story required).

0. Nothing known.
1. Any of crew not at crash stations.
2. Aircraft broke into fire on crashing.
3. Aircraft broke up on crashing.
4. Aircraft exploded on crashing.
5. Any of crew injured on crashing.
6. Any of crew killed on crashing.
7. Any of crew trapped in aircraft.
8. Was an attempt made to destroy aircraft and equipment.
9. Was this attempt successful.

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76. General difficulties - Baling out (tick all that apply).

Interrogator's Comments. (Full story - obstruction of exits, etc.).

Y. Back type 'chute worn by any of crew.
X. Seat type 'chute worn by any of crew.
0. Did any 'chutes open in aircraft.
1. Injuries while leaving aircraft.
2. Drill carried out incorrectly.
3. Order to abandon aircraft not given.
4. Order to abandon preceded by preparatory order.
5. Did anybody jam in hatch.
6. Was emergency signal used.
7. Other difficulties during abandonment.
8. Was George used successfully.
9. Was George used unsuccessfully.

77. Parachute descents.

Interrogator's Comments.

Y. Did any crew bale out from very low altitude.
X. Did any crew come down in unorthodox Attitude; state why.
0. Were there any injuries due to parachute pack.
1. Were there any injuries due to shroud lines.
2. Were there any injuries due to harness.
3. Were there any injuries on landing.
4. Did any 'chutes fail to open.
5. Were any 'chutes opened manually.
6. Were any helmets worn during descent.
7. Were there any injuries due to wearing of helmets.
8. Were any flying boots lost.
9. Were any 'chutes damaged.

78. General points - Ditching (tick all that apply).

Interrogator's Comments. (Height at which S.O.S. was sent, etc., - Full story required).

X. Any specific points not given below.
1. Was S.O.S. sent.
2. Were any of crew not at ditching stations.
3. Did dinghy release automatically.
4. Did anyone jam in hatch.
5. Did aircraft break in nose on impact.
6. Did aircraft break in fuselage on impact.
7. Did aircraft break at tail on impact.
8. Did aircraft sink in less than 1 minute.
9. Did aircraft sink in less than 3 minutes, but in more than 1 minute.

79. Experience of Pilot.

Interrogator's Comments.

Y. First tour.
X. Second or more tours.
0. Not known.
1. 0 - 5
2. 6 - 10
3. 11 - 15
4. 16 - 20
5. 21 - 25
6. 26 - 30
7. 31 - 35
8. 36 - 40
9. 40 +

(1–9: Give total operations for all tours.)

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80. Crew position of informant(s). (Tick all that apply). Interrogator's comments.

1. Pilot.
2. Navigator.
3. Wireless Operator.
4. Flight Engineer.
5. Air Bomber.
6. Mid-upper Gunner.
7. Rear Gunner.
8. Other.
9. Other.

COMMENTS OF INTERROGATOR

(Intelligence information of ground sources, etc., Comments on drills etc., other comments).

APPENDIX No. 5

FORM No. 12

MASTER CODE SHEET FOR RETURNED P.O.W's.

GENERAL INSTRUCTIONS TO CODERS

1. Read through the story assimilating the general outlines.

2. Read through the story again paying more attention to the details given.

3. On the code sheet complete:-

   I The card No.
   II Your coders No.

4. Read through the story again coding onto the requisite sheet as you go.

5. When you have coded the story, then -

I	Check that the columns marked 'A' have been coded.	All
II	Check that the columns marked 'B' are coded if Col. 45 is coded 1, 3, or 4.	Fighter
III	Check that the column marked 'C' is coded if Col. 45 is coded 3, 4, B, K or S.	Flak
IV	Check that the column marked 'D' is coded if Col. 45 is coded 7.	Bombs
V	Check that the column marked 'E' is coded if Col. 45 is coded 8.	Collisions
VI	Ensure that the columns marked 'P' have, if called for, one of Y, X or 0 coded and one number from 1 - 9 coded and check that they do not have more than one from each of the sets (Y-0, 1-9) coded.	
VII	Check that the Cols. marked 'Q' have only one number from 0-9 coded.	

6. Complete the coders proforma given you.

7. ABOVE ALL WHEN IN DOUBT - ASK.

APPENDIX No. 5

FORM No. 12 (Page 2)

PROPOSED METHOD FOR CHECKING 'K' REPORT CODING

1. ORGANISATION LAYOUT:-

Initial Coders

1st Cards punched and verified.

Secondary Coders

2nd Cards punched and verified.

Cards compared on all double-punched columns and discrepancies noted on to the proforma

Cards compared

Sorted to bring together those applying to some aircraft.

Cards listed on all single or alphabetically punched columns.

Clerk checks all discrepancies and puts them on to proforma.

All discrepancies passed to Specialised Coders for final coding.

Returned to clerk to put on to one copy of the original coding.

Final cards punched and verified.

Statistics produced for Final Cards.

NOTES:

1. The Initial and Secondary Coders shall work in separate rooms, the Secondary Coders working one day behind the Primary Coders. A proforma should be completed by the checking clerk for all cards which have discrepancies and passed to the Specialised Coders.

2. The Specialised Coders should be in a room with easy access to the files of 'K' Reports.

3. Each coder is to be given a number designated by X or Y.

4. The Specialised Coders will pass back the completed proformae to the checking clerk, who corrects the coding of any column requested on ONE copy of the original coding.

5. Corrected coding passed to Punch Operators.

APPENDIX No. 5

Form No. 12 (Page 3)

CODERS PRO FORMA

CODERS NAME ______________________ CODERS No. ______________

Date	CARD No.	A/C SQUAD.	LETTER	DATE AND TARGET

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MASTER CODE SHEET

General Card - Card No. 1

Column Number	Title	Coding	Remarks
39.	Type	1. Lancaster 2. Halifax 3. Stirling 4. Manchester 5. Wellington 6. Whitley 7. Hampden 8. Mosquito 9. Other types	Code one only
45.	Initial Cause of Loss	0. Unknown 1. Fighter 3. Fighter & Flak 4. Fighter or Flak (not known which) 5. Unintentional crash 6. Engine failure 7. Falling bombs 8. Collision 9. Other B. (Y2) Heavy flak K. (X2) Light flak S. (02) Flak (type unknown)	Code ohe only
46.	Final Cause of Loss (1st Column)	0. Unknown 1. Fire 2. Control Failure 3. Engine Failure 4. Aircraft un-airworthy 5. Fuel shortage 6. Explosion in Air 7. Other	(i) Whenever an aircraft is lost due to only one final cause, the cause is to be coded in the first and 8 coded in the second column. (ii) If it can be stated that the loss is directly attributable to two final causes (i.e. one without the other would have caused the loss) then the first column should be used for the primary cause and the second for the secondary cause. (iii) If it is thought that more than two factors caused the loss of the aircraft, ASK.
47.	Final cause of Loss (2nd Column)	0. Unknown 1. Fire 2. Control Failure 3. Engine Failure 4. Aircraft un-airworthy 5. Fuel shortage 6. Explosion in Air 7. Other 8. Only one final cause of loss	
48.	Weather at Time of Incident.	Y. Above X. Below 0. Not known if above or 1. Clear; no cloud. (below 2. Clear; above or below, haze or cloud. 3. Up to 5/10ths cloud 4. 6-9/10ths cloud 5. 10/10ths cloud	(i) Code one of Y-0 and one of 1-5 or code one of 6-9. (ii) If more than one incident, code for most serious only. (iii) Where 'no cloud' code 0.1.

..../Over

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Column Number	Title	Coding	Remarks
		6. Different amounts of cloud above and below or flying in cloud. 7. Icing experienced. 8. Atmospheric peculiarities other than icing experienced. 9. No information about the weather given.	
49.	Visibility at Time of Incident.	0. Visibility not known. 1. Visibility poor. 2. Visibility moderate. 3. Visibility good. 4. Visibility very good.	If more than one incident code for most serious only.
50.	State of Moon at Time of Incident.	0. State of Moon not known. 1. No moon up. 2. Half moon up. 3. Full or Nearly Full Moon up. 4. Daylight Operation.	If more than one incident code for most serious only.
51.	Position en route at Time of Incident.	Y. Orbiting, or Dog-Leg (Deliberate and Legitimate) X. Off route (Other than Y) or Off Time) 0. More than one incident 1. Outbound N.O.E.T. 2. Outbound O.E.T. more than 30 miles from the target. 3. Outbound O.E.T. less than 30 miles from the target. 4. Target area. 5. Homebound O.E.T. less than 30 miles from the target. 6. Homebound O.E.T. more than 20 miles from the target. 7. Homebound N.O.E.T. 8. Homebound (Intruder) 9. Other (with Spec. Ops. 100 Gp. etc.)	(i) If more than one incident, code for most serious only. (ii) Code one of 1-9 with one of Y-O, if applicable
54.	Evasive Action immediately before Incident	0. Not known 1. None. 2. Weaving. 3. Corkscrew. 4. Turn. 5. Dive. 6. Diving turn. 7. Climb. 8. Evasive action taken - Type not known.	(i) If more than one incident, code for the most serious only.
55.	Evasive Action during Incident.	0. Not known 1. None. 2. Weaving. 3. Corkscrew. 4. Turn. 5. Dive. 6. Diving turn. 7. Climb. 8. Evasive action taken - type not known	(i) If more than one incident, code for the most serious only.

Column Number	Title	Coding	Remarks
56.	Silhouette, Searchlights, etc., at time of Incident.	X. Daylight Operation 0. Not known 1. No silhouette, no searchlight. 2. Illuminated by single searchlight. 3. Coned by searchlights 4. Silhouette against searchlights on ground. 5. Silhouette against burning flares, fires or lights on ground. 6. Silhouette against illuminated cloud. 7. Silhouette against light part of the sky. 8. Silhouette against the moon. 9. Silhouette against fighter flares near.	(i) If more than one incident, code for the most serious only. (ii) Code one of X-9 only.

FIGHTER LOSSES ONLY

THIS SECTION IS TO BE CODED ONLY IF THE AIRCRAFT WAS LOST DUE ENTIRELY OR IN PART TO FIGHTERS (i.e. initial cause of loss coded as either 1, 3, or 4 in Section 45).

NOTE I. If the aircraft suffered two distinct attacks, always code for most serious only.

NOTE II. If more than one aircraft made the attack at the same time, always code for the first one seen.

Column Number	Title	Coding	Remarks
57.	Fighter Type.	Y. More than one aircraft attacked. 0. Nothing known. 1. No visual. Not seen on Spec. Equip. 2. No visual. Seen on Spec. Equip. 3. Visual. Not identified. 4. Enemy. Single engined. 5. " Twin " 6. " Four " 7. " Jet propelled. 8. " Friendly type. 9. Other.	Note. If more than one aircraft made the attack code Y and one of 1-9.
58.	Direction of attack.	Y. Above. X. Level 0. Below. 1. Dead ahead. 2. Starboard Bow. 3. Starboard beam. 4. Starboard Quarter. 5. Dead Astern.	Dead ahead.

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Column Number	Title	Coding	Remarks
58 (cont'd)		6. Port Quarter 7. Port Beam 8. Port Bow 9. Nothing known	(ii) Code one of Y - 0 and one of 1 - 9 OR 9 only.
59.	Position of First Fighter	Y. Fighter seen by direct illumination X. Fighter seen by Silhouette. 0. Not known whether direct illumination or silhouette. 1. Rear Turret. 2. Mid-Upper Turret. 3. Mid-Under Position 4. Astrodome 5. Pilot's cockpit 6. Air Bomber's compartment. 7. Not sighted 8. Other 9. Not known who first sighted enemy a/c	(i) Code one of Y - 0 and one of 1 - 9 (ii) If both M.U/G and R/G sight simultaneously, code as M.U/G.
60.	Combat	Y. Surprise attack (No warning before firing X. Not surprise attack 0. Not known if surprise 1. Bomber did not fire 2. Bomber fired first, fighter second. 3. Bomber and fighter fired simultaneously. 4. Fighter fired first, bomber second. 5. Both fired, order unknown. 6. Not known if bomber fired, but fighter fired first. 7. Nothing known.	Note. Code Y - 0 and one of 1 - 7
61.	Rear Guns and Turret	Y. Rear guns not manned at time of attack X. Turret u/s by E/A before firing 0. Not known 1. Guns unserviceable before attack 2. Turret hydraulics u/s before attack 3. Turret electrics u/s before attack 4. Serviceable but not used. 5. Serviceable and used 6. Guns jammed 7. Guns damaged by E/A. 8. Hydraulics damaged by E/A. 9. Electrics damaged by E/A.	Note. Code all that apply.

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Column Number	Title	Coding	
62.	Mid-upper Guns and turret.	Y. Mid-upper guns not manned at time of attack. X. Turret made unserviceable by enemy action before firing. 0. Not known. 1. Guns unserviceable before attack. 2. Turret hydraulics unserviceable before attack. 3. Turret electrics unserviceable before attack. 4. Serviceable but not used. 5. Serviceable and used. 6. Guns jammed. 7. Guns damaged by enemy action. 8. Hydraulics damaged by enemy action. 9. Electrics damaged by enemy action.	NOTE:- Code all that apply.
63.	Armament used by fighter.	Y. Tracer used. X. Tracer not used. 0. Not known if tracer used. 1. Machine guns used. 2. Cannon used. 3. Machine guns and cannon used. 4. Rocket projectiles used. 5. Upward firing guns used. 6. Not known what sort of guns used.	NOTE:- Code Y - 0 and one of 1 - 6.

FLAK LOSSES ONLY.

THIS SECTION IS TO BE CODED ONLY IF THE AIRCRAFT WAS LOST DUE ENTIRELY OR IN PART TO FLAK. (i.e. initial cause of loss coded as 3, 4, B, K or S) - Col.45.

If the aircraft was involved in two distinct incidents, code always for the more serious only.

Column Number	Title	Coding	
64.	Type of Flak.	Y. Direct strike. X. Near Miss. 0. Wide miss. 1. Damage due to one shell. 2. Damage due to two shells. 3. Damage due to three shells. 4. Damage due to more than three shells. 6. Damage due to unknown number of shells. 5. Damaged, but nothing further known.	NOTE:- Code one of Y - 0 and one of 1 - 4; 6 or code 5.

LOSSES TO INCENDIARY OR H.E. BOMBS ONLY.

THIS SECTION IS TO BE CODED ONLY IF THE AIRCRAFT WAS LOST DUE ENTIRELY TO BOMBS FALLING FROM ABOVE (i.e. initial loss coded as 7).

If the aircraft was involved in two incidents, code for the most serious only.

FORM No. 12 (Page 9)

Column Number	Title	Coding	Remarks
65.		Y. Hit by 1 incendiary bomb. X. Hit by more than 1 Incendiary bomb. 0. Hit by unopened incendiary cluster. 1. Bombs ignited on impact and caused fire. 2. Bombs ignited on impact but did not cause fire. 3. Bombs ignited on impact and not known if fire caused. 4. Not known if bombs ignited but fire caused. 5. Hit by Incendiaries but nothing further known. 6. Hit by H.E. bomb.	Code one of Y-0 and one of 1-5 OR code 6.

LOSSES TO COLLISION ONLY

THIS SECTION IS ONLY TO BE CODED IF THE AIRCRAFT WAS LOST DUE ENTIRELY TO A COLLISION (i.e. initial cause of loss coded as 8). Col. 45.

If the aircraft was involved in two incidents code for the most serious only.

Column Number	Title	Coding	Remarks
66.		Y. Other aircraft visibile before collision avoiding action taken X. Other aircraft visible before collision no avoiding action taken. 0. Other aircraft visible before the collision, not known if avoiding action taken. 1. Other aircraft approached from the ahead above. 2. " " approached from the ahead below. 3. " " approached from the beam above. 4. " " approached from the beam below. 5. " " approached from the astern above. 6. " " approached from the astern below. 7. Other aircraft visible, direction unknown. 8. Not known if other aircraft visible. 9. Other aircraft not visible.	Code one of Y - 0 and one of 1 - 7 or code one of 2, 8 - 9½
67.	Radio and Electrics.	X. None of 1 - 9 0. Nothing known. 1. W/T hit. 2. Intercom. unserviceable before attack. 3. Intercom. made u/s during attack 4. Emergency call light system hit or u/s. 5. Gee hit. 6. H2S or H2X hit. 7. General electric services failed. 8. Bomb fusing and release gear hit 9. Minor electric services(Lamps, etc.) hit.	Code all that apply

FORM No. 12 (Page 10)

Column Number	Title	Coding	Remarks
68.	Location of Fires.	Y. Fuselage fire. X. Wing fire. 0. Fire but location not known. 1. Petrol. 2. Oil. 3. Hydraulic fluid or wind-screen glycol. 4. Pyrotechnic stores. 5. Incendiary bombs. (Not from other aircraft). 6. Engines. 7. Electric and radar. 8. Window stored in fuselage. 9. No fire.	Code all that apply.
69.	Controls Failure.	Y. Aircraft uncontrollable X. Aircraft in limited control. 0. Not known if under control. 1. Aircraft straight and level. 2. Aircraft in spin. 3. Aircraft in dive. 4. Aircraft in diving turn. 5. Aircraft climbing. 6. Aircraft in other attitudes. 8. Attitude not known. 9. A/C under full control.	Code one of Y - 0 and one of 1 - 8 OR code 9.
70.	Fuel Shortage	X. If aircraft abandoned solely because of F/S (cross check with Final Cause of Loss.) 0. Not known if there was fuel shortage. 1. Due to holing of tanks. 2. Due to holing of pipes. 3. If not (1) or (2) due to overconsumption. 4. If not (1) or (2) due to mismanipulation. 5. If not (1) or (2) due to deviation from planned flying schedule. 6. Due to leak - not e/a. 7. No fuel shortage. 8. Fuel shortage not given in 0 - 7.	
71.	Distance between Incident and Loss (Miles)	1. 25 or less 2. 26 - 50 3. 51 - 75 4. 76 - 100 5. 101 - 125 6. 126 - 150 7. 151 - 175 8. 176 - 200 9. Over 200.	If not stated estimat from time (3-4 miles per minute).

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Column Number	Title	Coding	Remarks
72	Was there any explosion?	Y. Fire after explosion. X. Fire before explosion. 0. Not known if fire before or after explosion. 1. In the air before baling out. 2. In the air during baling out. 3. In the air after baling out. 4. On the ground. 5. No explosion. 6. More than one explosion. 7. Explosion caused break-up of aircraft. 8. Explosion broke off wing or part of wing. 9. Not known whether any explosion	Code all that apply.
73	Action taken by crew.	Y. Aircraft known to be completely destroyed or sunk. X. Aircraft known to have escaped destruction. 1. Baled out. 2. Ditched. 3. Crashed intentionally. 4. Crashed unintentionally. 5. Baled out and ditched. 6. Baled out and crashed. 7. Blown out of aircraft by explosion. 8. Other action not covered by 1 - 7. 9. Baled out and blown out.	Code 1-8 and one of Y and X, if applicable.
74	Hatch troubles	Y. Not known. X. No hatch troubles. 0. F.E.H. jammed temporarily. 1. F.E.H. jammed permanently. 2. R.E.H. jammed temporarily. 3. R.E.H. jammed permanently. 4. Top R.E.H. jammed temporarily. 5. Top R.E.H. jammed permanently. 6. Top M.E.H. jammed temporarily. 7. Top M.E.H. jammed permanently. 8. Pilot's hatch jammed temporarily. 9. Pilot's hatch jammed permanently.	Code all that apply.
75	CRASHES. General Points.	Y. Crash landed - no trouble. X. Did not crash land. 0. Not known if attempted to crash land. 1. Any of crew not at crash stations. 2. A/C broke into fire on crashing. 3. A/C broke up on crashing. 4. A/C exploded on crashing. 5. Any of crew injured on impact. 6. Any of crew killed on impact. 7. Any of crew trapped in aircraft. 8. An attempt was made to destroy aircraft and equipment. 9. This attempt was successful.	Code all that apply.

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APPENDIX No. 5

Column Number	Title	Coding	Remarks
76	BALING OUT. General Diffioulties.	Y. Back type 'chute worn by any of crew X. Seat type 'chute worn by any of crew 0. Did any chutes open in aircraft? 1. Injuries while leaving aircraft. 2. Drill carried out incorrectly. 3. Order to abandon A/C not given. 4. Did anybody jam in hatch? 5. Was emergency signal used? 6. Other difficulties during abandonment 7. Was 'George' used successfully? 8. Was 'George' used unsuccessfully? 9. No difficulties as crew baled out.	Code all that apply.
77	Parachute Descents.	Y. Did any crew bale out from very low altitudes? (less than 1000') X. Did any crew come down in unorthodox attitude or unconscious during descent. 0. Were there any injuries due to parachute pack? 1. Were there any injuries due to shroud lines? 2. " " " " " to harness? 3. " " " " on landing? 4. Did any 'chutes fail to open? 5. Were any 'chutes opened manually? 6. Were there any injuries due to wearing of helmets? 7. No parachuting difficulties. 8. Were any 'chutes damaged? 9. No story or no parachute descent.	Code all that apply
78	General Points - Ditching.	X. Any specific points not given below. 0. Did not ditch. 1. S.O.S. sent? 2. Were any of the crew not at ditching Stations? 3. Did dinghy release automatically? 4. Did anyone jam in hatch? 5. Did aircraft break at nose on impact? 6. Did a/c break in fuselage on impact? 7. Did a/c break at tail on impact? 8. Did a/c sink in less than 1 minute? 9. Did a/c sink in less than 3 min, but in more than 1 minute?	Code all that apply
79	Experience of Pilot.	Y. First tour. X. More than one tour. 0. Not known. 1. 0 - 5. 2. 6 - 10. 3. 11 - 15. 4. 16 - 20. 5. 21 - 25. 6. 26 - 30. 7. 31 - 35. 8. 36 - 40. 9. 41 or MORE.	Code Y or X and then 1 - 9 as number of trips in current tour or code 0.

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Column Number	Title	Coding	Remarks
80.	Crew Position of Informants.	1. Pilot 2. Navigator. 3. Wireless Operator. 4. Flight Engineer. 5. A/B. 6. M/U/G. 7. R/G. 8. Other. 9. Other.	Code all that apply

APPENDIX No. 5

Form No. 12 (Page 14)

PERSONNEL CASUALTIES CARD: CARD No. 2

Column Number	Title	Coding	Remarks
57 60 63 66 69 72 75 78	Crew Casualties by Positions Col. 1 Main information and injuries due to E/action in the air	Y. Evaded X. Killed or missing (died of wounds) 0. P.O.W. 1. Unhurt (by any cause) 2. Slight injury due to e/a in the air. 3. Serious injury due to e/a in the air. 4. Killed due to e/a in the air. 5. Injured or killed, but not due to e/a in the air. 6. Injured or killed but not known if due to e/a in the air. 7. Not known if injured or uninjured. 8. Nothing known of crew member. 9. Crew position not filled.	Code one of Y-0 and one of 1-8 or code 9.
58 61 64 67 70 73 76 79	Crew casualties by Positions Col. 2 Injuries due to non-enemy action and to abandonment.	1. No injury due to NEA in the air. 2. Slight injury due to NEA in the air. 3. Serious injury due to NEA in the air. 4. Killed due to NEA in the air. 5. No known injury due to NEA in the air. 6. Killed in the air, cause unknown. 9. Crew position not filled.	Code one of these only. X. not occupying position for which coded.
59. 62 65 68 71 74 77 80	Crew casualties by Positions Col. 3 Injuries after abandoning aircraft and parachuting	Y. Died of wounds X. Killed in air 0. Unhurt after baling out 1. Unhurt after crashing or ditching. 2. Slight injury after baling out. 3. Slight injury after crashing or ditching. 4. Serious injury after baling out. 5. Serious injury after crashing or ditching 6. Killed after baling out 7. Killed after crashing or ditching. 8. Dead on ground no details known. 9. Crew position not filled.	Code one of these only - or code Y and one of 2-5 if applicable.

/ If

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Form No. 12 (Page 14 contd)

If the case arises of a man dying directly as a result of wounds received at any time in the incident, code as follows:-

1st. Col. X, and the appropriate category (1-8) which describes the injury. (If applicable).

2nd. Col. The category describing the injury. (If applicable).

3rd. Col. Y, and the appropriate category (0-8) which describes the injury. (If applicable).

That is to say, 'Y = Died of wounds' should be added to col. 3, and the man should otherwise be coded as if injured, except for being listed X in col. 1.

2nd col. X in col. 2 Code X in this col. if there is more than one extra crew member (normally classified as other) and a spare crew position not filled. Code details for extra man under spare crew position.

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SPECIAL EQUIPMENT DAMAGE CARDS: CARD No. 3

Column Number		Coding	Remarks
55	Monica or Fishpond	0. A/C equipped with Vis. Monica (III or V) Y. A/C equipped with Monica Aural (1) or Type unknown. X. A/C equipped with Fishpond. 1. Switched off. 2. Unserviceable. 3. Gave first warning. 4. Warned later. 5. Gave no warning. 6. Not watched or used. 7. Nothing known about equipment though carried. 8. A/C not equipped with either Fishpond or Monica. 9. Monica pipping continuously.	Code either Y or 0 or X and one 1-7, or code 8.
56	A.G.L.T. or Boozer	Y. A.G.L.T. carried. X. Boozer carried. 1. Switched off. 2. Unserviceable. 3. Gave first warning. 4. Warned later. 5. Gave no warning. 6. Not used or watched. 7. Nothing known about equipment though carried. 8. A/C not equipped with either A.G.L.T. or Boozer.	Code either Y or X and one of 1-7, or code 8.
57	H2S or H2X or Oboe Code as 3 if u/s.	Y. A/C equipped with H2S (H2S.Mk.II) X. A/C equipped with H2X (H2S.Mk.III) 1. H2S switched on. 2. H2S switched off. 3. Condition of H2S not known or u/s. 4. H2S or H2X not carried, but Oboe carried. 5. None of H2S, H2X or Oboe carried.	Code either Y or X and one of 1-3, or code 4 or 5.
58	Carpet or Type Z Telescope	Y. Carpet. X. Type Z telescope 1. Carpet switched on, jamming. 2. " " " sweeping. 3. " " " performance unknown. 4. Carpet switched off. 5. State of Carpet not known. 6. Type Z telescope unserviceable. 7. A/C identified as hostile on type Z telescope. 8. A/C not identified on type Z telescope. 9. Type Z not used or nothing known about type Z telescope.	(i) Code Y and one of 1-5. for Carpet A/C. (ii) Code X and one of 6-9 only for A/C equipped with A.G.L.T.

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SPECIAL EQUIPMENT DAMAGE CARD: CARD No. 3 Cont.

Column Number	Title	Coding	Remarks
59	Aileron Controls	Y. Control mechanism hit. X. Control surface hit. 0. Control mechanism and surface hit. 1. Controls damaged but still partially effective. 2. Controls damaged and ineffective. 3. Hit, but no details known. 4. Controls effective, not known if hit. 6. Nothing known. 7. Not hit. 8. Some controls damaged, not known if aileron.	Code one of Y-0 and either 1 or 2 OR code one of 3-8.
60	Elevator Controls	Y. Control mechanism hit. X. Control surface hit. 0. Control mechanism and surface hit. 1. Controls damaged but still partially effective. 2. Controls damaged and ineffective 3. Hit, but no details known. 4. Controls effective, not known if hit. 6. Nothing known. 7. Not hit. 8. Some controls damage not known if elevator.	Code one of Y-0 and either 1 or 2 OR code one of 3-8.
61	Rudder Controls	Y. Control mechanism hit. X. Control surface hit. 0. Control mechanism and surface hit. 1. Controls damaged but still partially effective 2. Controls damaged and ineffective. 3. Hit, but no details known. 4. Controls effective, not known if hit. 6. Nothing known. 7. Not hit. 8. Some controls hit, not known if rudder.	Code one of Y-0 and either 1 or 2 OR code one of 3-8.
62	Fuel System	Y. Nitrogen tanks not filled X. Nitrogen filled tanks. 0. Nothing known. 1. Not hit. 2. Tanks hit, fuel lost. 3. Tanks hit, on fire. 4. Tanks hit, exploded. 5. Main fuel pipe hit. 6. Fuel controls hit. 7. Tanks hit known to be empty. 8. Tanks hit known to be partially filled with petrol. 9. Tanks hit known to be completely filled with petrol.	Code all that apply.

APPENDIX No. 5

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SPECIAL EQUIPMENT DAMAGE CARD: CARD No. 3 Cont.

Column Number	Title	Coding	Remarks
63	Hydraulics.	Y. Hydraulics or electrics u/s due to engine failure.	(Code 0-9 if applicable)
		0. Nothing known	Code all that apply.
		1. Not hit.	
		2. Main hydraulic hit.	
		3. Landing services (flaps & u/c) hit.	
		4. Turret hydraulics or electrics hit.	
		5. Emergency hydraulics hit.	
		6. Other hydraulics hit.	
		7. Hydraulic fire (also code Col. 68)	
		8. Hydraulic fluid lost.	
		9. Unable to open or shut bomb doors. (Applicable also to electric bomb doors)	
64	Bombs, etc. carried on own aircraft.	0. Nothing known.	Code all that apply.
		1. Not hit.	
		2. Bombs on fire.	
		3. Bombs exploded.	
		4. Flares on fire.	
		5. Flares exploded.	
		6. Ammunition on fire.	
		7. Ammunition exploded.	
		8. Photoflash exploded.	
		9. Bombs not carried at time of incident.	
65	Oil System.	0. Nothing known.	Code all that apply.
		1. Not hit.	
		2. Tank hit.	
		3. Pipes hit.	
		4. Oil Cooler hit.	
		5. Oil system hit, no details known.	
		6. Oil fire (also code Col. 68).	
		7. Fall in oil pressure observed, followed by seizure.	
		8. Fall in oil pressure observed, engine feathered before seizure.	
		9. Fall in oil pressure observed, engine continued running.	
66	Instruments and other services	Y. Nothing known.	Code all that apply.
		X. Instruments not hit.	
		0. Navigational instruments hit or u/s.	
		1. Blind flying instruments hit or u/s.	
		2. Engineer's instruments hit or u/s	
		3. Oxygen system, high pressure damaged.	
		4. Oxygen system, low pressure damaged.	
		5. Oxygen bottles exploded.	
		6. Pneumatic system hit.	
		7. Vacuum system (pesco pump) hit.	
		8. 'George' hit, or u/s.	
		9. Other instruments or services hit or u/s.)	

APPENDIX No. 5

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SPECIAL EQUIPMENT DAMAGE CARD: CARD No. 3 Cont.

Column Number	Title	Coding	Remarks
67	Airframe and Non-localised Damage.	0. Nothing known.	
		1. No damage to airframe.	
		2. Wing surface damaged.	
		3. Wing main spar damaged.	
		4. Large part of wing severed.	
		5. Tail unit surface damaged.	
		6. Large part of tail unit severed.	Code all that apply.
		7. Fuselage surface damaged, (including pilot's and bomb aimer's perspex).	
		8. Extensive damage to interior of fuselage.	
		9. Aircraft came to pieces in the air.	

ENGINES (Code each engine). (For Twin/Engine code PI and SI. For Single/Engine code PI only).

Column Number	Title	Coding	Remarks
P.O.68 P.I.71 S.I.74 S.O.77	Engine damage and failure	Y. Due to E/A.	
		X. Not due to E/A.	
		0. Not known if due to E/A.	
		1. Coolant system damaged.	
		2. Engine control system damaged.	
		3. Propeller damaged or fell off.	Code one of Y-0 (the most serious) and those applicable in 1-9.
		4. Engine acces: damaged (ie.CSU etc.	
		5. Loss of Boost.	
		6. Loss of fluctuation of revs.	
		7. Loss of oil pressure.	
		8. Engine ran away.	
		9. Damage or failure, no details known.	
P.O.69 P.I.72 S.I.75 S.O.78	Engine Fires	Y. Due to E/A.	
		X. Not due to E/A.	
		0. Not known if due to E/A.	
		1. Engine feathered successfully.	
		2. Unable to feather.	
		3. Did not attempt to feather.	Code one of Y-0 (the most serious) and those applicable in 1-9.
		4. Unfeathered spontaneously.	
		5. Attempt made to restart after feathering.	
		6. Grav. Successful.	
		7. Grav. unsuccessful.	
		8. Grav. not used.	
		9. On fire.	
P.O.70 P.I.73 S.I.76 S.O.79	Engines. Gen.	Y. Enemy action.	
		X. Not enemy action.	
		0. Not known if due to enemy action	
		1. Order of fire drill correct. (feather, stop, graviner).	Code all that apply.
		2. Order of fire drill incorrect.	
		3. Fire drill: nothing known.	
		4. Cut, not on fire.	
		5. Excess vibration.	
		6. No fire drill attempted.	

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SPECIAL EQUIPMENT DAMAGE CARD: CARD No. 3 Cont.

ENGINES (Code each engine)

Column Number	Title	Coding		Remarks
80	Fires General	X.	Not known which engine failed or damaged (Convention Code P.O., P.I., S.I., etc. for 1, 2 or 3 in order).	(Convention as above)
		9.	Not known which engine on fire.	" "
		Y.	Dived in attempt to put out fire.	Code all that apply.
		0.	Other extinguisher used successfully (non-engine fire).	
		1.	Other extinguisher used unsuccessfully (non-engine fire).	
		2.	Aircraft airworthy in spite of non-engine fire.	
		3.	Aircraft not airworthy due to non-engine fire.	
		4.	Asphyxiating fumes in fuselage.	
		5.	No engines damaged or failed.	
		6.	No engines on fire.	
		7.	Fire originated in engines.	
		8.	Engine fire or failure distinct from cause of loss and no fire or failure during incident.	

If nothing known at all about engines code 9 on this column, and nothing on other columns for engines.

If engines were on fire code 9 on this column and code in order P.O., P.I., S.I., S.O., on the columns.

If engines damaged or failed code X and code in same order.

CODING SHEET No. 1

General Card - Card No. 1

	Card No.	Coders No.	Aircraft				Date and Target	Init.Loss	Final Loss		Details of Incident								A/C lost to fighters only						
			Sqdn.	Ltr.	Type	Mark			(1)	(2)	Weather	Vis.	Moon	Pos.	Feet 1000	E/Act. Bef.	E/Act. Aft.	S/Ls.	E/A Type	Dir. of Attack	1st sighting	Combat	Turrets R	Turrets MU	E/A Arm.
Col.Nos.	32	33	34-36	37-38	39	-40	41 - 44	45	46	47	48	49	50	51	52-53	54	55	56	57	58	59	60	61	62	63
1	1																								
2	1																								
3	1																								
4	1																								
5	1																								
6	1																								
7	1																								
8	1																								
9	1																								
		A P	A Q	A Q	A Q	A Q	A	A Q	A Q	A Q	A P	A Q	A Q	A P	A Q	A Q	A Q	A Q	B P	B P	B P	B P	B	B	B P

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APPENDIX No. 5

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CODING SHEET I (contd.)

General Card - Card No. 1

	Flak Losses only	Hit by Bombs only	Collis-ion only	Damage to Electrics	Fires Loca-tion	Control Failure	Fuel Short-age	Dist.	Expl.	Aband.	Hatches	Crashes	Bale Out	Para. Descent	Ditch-ing	Pilots Exp.	Inform-ants
	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
	C P	D P	F P	A	A	A P	A P	A Q	A Q	A P	A	A	A	A	A	A P	A

CODING SHEET No. 2

Personnel Casualties - Card No. 2

			Aircraft			Crew Totals						Casualties by Crew Positions																							
												Pilot			Nav.			W/Op.			F/Eng.			A/B			M/U/G			R/G			Other		
	Card No.	Coders No.	Sqdn.	Letter	Date and Target	In a/c	Killed	Ser.Inj.	Sl. Inj.	Unhurt	Not known	EA	NEA	ABAND	EA	NEA	ABAND	EA	NEA	ABAND	EA	NEA	ABAND	EA	NEA	ABAND	EA	NEA	ABAND	EA	NEA	ABAND	EA	NEA	ABAND
Col. No.	40	41	42-44	45, 46	47-50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	2																																		
2	2																																		
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4	2																																		
5	2																																		
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7	2																																		
8	2																																		
9	2																																		
	2																																		
		A P	A	A	A	A Q	A Q	A Q	A Q	A Q	A Q	A P	A Q	A Q	A P	A Q	A Q	A P	A Q	A Q	A P	A Q	A Q	A P	A Q	A Q	A P	A Q	A Q	A P	A Q	A Q	A P	A Q	A Q

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APPENDIX No. 5

CODING SHEET No. 3

Special Equipment & Damage Card - Card No. 3

	Card No.	Coders No.	Aircraft		Date and Target	Special Equip.				Controls			Miscellaneous						Engines												Fires General
																			P.O.			P.I.			S.I.			S.O.			
			Sqdn.	Letter		Monica & Fishpond	AGLT & Boozer	H2S, H2X OBOE	Carpet Type Z	Ail.	Elev.	Rud.	Fuel	Hydr.	Bombs	Oil	Inst.	Air Fr.	Dam. Fail.	Fires	Gen.	Dam. Fail.	Fires	Gen.	Dam. Fail.	Fires	Gen.	Dam. Fail.	Fires	Gen.	
Col. No.	44	45	46-48	49-50	51-54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
1	3																														
2	3																														
3	3																														
4	3																														
5	3																														
6	3																														
7	3																														
8	3																														
9	3																														
		A	A	A	A	A P	A P	A P	A P	A P	A P	A P	A	A	A	A	A	A	P	P	P	P	P	P	P	P	P	P	P	P	

APPENDIX No. 5

Form No. 13

FINAL P.O.W. CARDS

Column numbers only - for coding, see against old column numbers in Form No. 12.

Card 5 (original Cards 1 and 2 combined)

Column No.	Information Required		Old Card and Column No.
1	5 - Card type		Gang punched
2-4	Squadron		1 (34-36)
5, 6	Letter		1 (37, 38)
7	Type		1 (39)
8	Mark		1 (40)
9-12	Date and Target		1 (41-44)
13	Init. Loss		1 (45)
14-15	Final Loss		1 (46, 47)
16	Weather	Details of Incident	1 (48)
17	Visibility	Details of Incident	1 (49)
18	Moon	Details of Incident	1 (50)
19	Position en Route	Details of Incident	1 (51)
20,21	Height of Incident	Details of Incident	1 (52, 55)
22,23	Evasive action	Details of Incident	1 (54, 55)
24	Searchlights etc.	Details of Incident	1 (56)
25	Enemy Aircraft type	Losses to Fighters	1 (57)
26	Direction of Attack	Losses to Fighters	1 (58)
27	Position of First Sighter	Losses to Fighters	1 (59)
28	Details of Combat	Losses to Fighters	1 (60)
29	Rear Turrets	Losses to Fighters	1 (61)
30	M/U Turrets	Losses to Fighters	1 (62)
31	Enemy Aircraft's Armament	Losses to Fighters	1 (63)
32	Losses to flak		1 (64)
33	Losses to Falling Bombs		1 (65)
34	Losses to Collision		1 (66)
35	Damage to Electrics		1 (67)
36	Location of Fires		1 (68)
37	Control Failures		1 (69)
38	Fuel Shortage		1 (70)
39	Distance from Incident to Loss		1 (71)
40	Explosions		1 (72)

APPENDIX No. 5

Form No. 13 (Page 2)

Column No.		Information Required		Old Card and Column No.
41		Method of Abandoning		1 (73)
42		Hatch Troubles		1 (74)
43		Crashes		1 (75)
44		Baling out Difficulties		1 (76)
45		Parachute Descents		1 (77)
46		Ditching		1 (78)
47		Pilot's Experience		1 (79)
48		Crew Positions of Informants		1 (80)
51		In aircraft		2 (51)
52		Killed		2 (52)
53		Seriously injured		2 (53)
54		Slightly injured		2 (54)
55		Unhurt		2 (55)
56		Not Known		2 (56)
57	Pilot	E/A Casualties	Casualties by crew Positions	2 (57)
58	Pilot	NEA Casualties		2 (58)
59	Pilot	Abandoning Casualties		2 (59)
60	Navigator	E/A Casualties		2 (60)
61	Navigator	NEA Casualties		2 (61)
62	Navigator	Abandoning Casualties		2 (62)
63	W/Operator	E/A Casualties		2 (63)
64	W/Operator	NEA Casualties		2 (64)
65	W/Operator	Abandoning Casualties		2 (65)
66	F/Engineer	E/A Casualties		2 (66)
67	F/Engineer	NEA Casualties		2 (67)
68	F/Engineer	Abandoning Casualties		2 (68)
69	Air Bomber	E/A Casualties		2 (69)
70	Air Bomber	NEA Casualties		2 (70)
71	Air Bomber	Abandoning Casualties		2 (71)
72	M/U/G	E/A Casualties		2 (72)
73	M/U/G	NEA Casualties		2 (73)
74	M/U/G	Abandoning Casualties		2 (74)
75	R/Gunner	E/A Casualties		2 (75)
76	R/Gunner	NEA Casualties		2 (76)
77	R/Gunner	Abandoning Casualties		2 (77)

APPENDIX No. 5

Form No. 13 (Page 3)

Column No.	Information Required		Old Card and Column No.
78	E/A Casualties	Casualties by Crew Positions (Contd.)	2 (78)
79	NEA Casualties		2 (79)
80	Abandoning Casualties		2 (80)

NOTE When producing these cards, Cards No. 1 and 2 were sorted into the same order. Card No. 1 was reproduced on to a blank card on the column given above. Card No. 2 was then reproduced on to the corresponding new cards and the date, target, squadron and letter plugged for checking, but not punching. This ensured that the two sets of information on the new card applied to the same aircraft.

Card 6. (Original Cards 1 and 3 combined)

Column No.		Information Required		Old Card and Column No.
1		6 card type		Gang punch
2-48		As given for Card 5		1 (34-80)
55		Monica and Fishpond	Special Equipment	3 (55)
56		AGLT and Boozer		3 (56)
57		H2S, H2X, and Oboe		3 (57)
58		Carpet and Type Z		3 (58)
59		Ailerons	Control Damage	3 (59)
60		Elevators		3 (60)
61		Rudder		3 (61)
62		Fuel System	Damage	3 (62)
63		Hydraulic System		3 (63)
64		Bombs		3 (64)
65		Oil System		3 (65)
66		Instruments		3 (66)
67		Air Frame		3 (67)
68	P.O.	Damage or Failure	Engine Damage	3 (68)
69		Fire		3 (69)
70		General		3 (70)
71	P.I.	Damage or Failure		3 (71)
72		Fire		3 (72)
73		General		3 (73)
74	S.I.	Damage or Failure		3 (74)
75		Fire		3 (75)
76		General		3 (76)

APPENDIX No. 5

Form No. 13 (Page 4)

Column No.		Information Required		Old Card and Column No.
77	S.O.	Damage or Failure	Engine Damage (Cont.)	3 (77)
78		Fire		3 (78)
79		General		3 (79)
80		Fires General		3 (80)

NOTE When producing these Cards, Cards No. 1 and 3 were sorted into the same order. Card No. 1 was reproduced on to a blank card on the columns given above. Card No. 3 was then reproduced on to the corresponding new cards, and the date, target, squadron, and letter plugged for checking but not punching. This ensured that the two sets of information on the new card applied to the same aircraft.

Card X-5 (Part of Original Card No. 4)

Column No.	Information Required	Old Card and Column No.
1	X-5 (Card type)	Gang punch
2-4	Squadron	37-39
5,6	Letter	40, 41
7	Type	35
8	Mark	36
9-12	Date and Target	31-34
13	Initial Loss	78
49	Bodies washed up	77
50	Explosions	80
51-80	As Cols. 51-80 on Card 5.	47-76

Card X-6 (Part of Original Card No. 4)

1	X-6 (Card type)	Gang punch
2-4	Squadron	37-39
5,6	Letter	40, 41
7	Type	35
8	Mark	36
9-12	Date and Target	31-34
13	Initial Loss	78
49	Fires	79
50	Explosions	80
51	Nitrogen Tank Equipment	46
55-58	As Cols. 55-58 on Card 6.	42-45

APPENDIX No. 5

FORM No. 14, SHOWING A SPECIMEN LIST AND TABULATION

APPENDIX No. 5

Form No. 14

LIST AND TABULATION FOR SPECIAL EQUIPMENT ANALYSIS

List:-

A/C Serial No.	A/C Letter	Special Equipment									A/C Type	A/C Mark	Result of Mission	A/C Group	Date	Target	Sqdn. No./ Sorties per Squadron
		Col. 38	Col. 39	Col. 40	Col. 41	Col. 42	Col. 43	Col. 44	Col. 45	Col. 46							
KB 0778	Y 0	1	0	1							1	0	1	6	3 0	3 3 4	4 2 8
KB 0771	Z 0	1	0	1							1	0	1	6			
NR 0196	A 0	1	0	1			1	0			2	3	1	6	3 0	3 3 4	2 4 2 9
MZ 0474	B 0	1	0	1			1	0			2	3	1	6			
MZ 0987	D 0	1	0	1							2	3	1	6			
MZ 0318	F 0	1	0	1							2	3	1	6			
MZ 0478	G 0	1	0	1			1	0			2	3	1	6			
MZ 0463	J 0	1	0	1							2	3	1	6			
LV 0994	L 0	1	0	1			1	0			2	3	1	6			
MZ 0285	0 0	1	0	1							2	3	1	6			
LW 0139	P 0	1	0	1							2	3	1	6			
NP 0946	S 0	1	0	1			1	0			2	3	1	6	/		
MZ 0865	V 0	1	0	1			1	0			2	3	1	6			
MZ 0411	W 0	1	0	1							2	3	9	6			
NB 2222	X 0	1	0	1			1	0			2	3	1	6			
NB 1212	Z 0	1	0	1							2	3	2	6			
ND 0591	A 0	1	0	2	9	0	0	0			1	3	1	8	3 0	3 3 4	2 1 5 6
PB 0468	B 0	1	0	2	5	0	1	0			1	3	1	8			
PB 0765	C 0	1	0	2	9	0	1	0			1	3	1	8			
PB 0611	D 0	1	0	2	9	0	0	0			1	3	1	8			
PB 0403	F 0	1	0	2	5	0	1	0			1	3	1	8			
PB 0186	G 0	1	0	2	9	0	1	0			1	3	1	8			
ND 0929	K 0	1	0	2	9	0	1	0			1	3	1	8			
PB 0402	M 0	1	0	2	9	0	0	0			1	3	1	8	3 0	3 3 4	7 4 0 5
PB 0233	0 0	0	1	2		1	0	0			1	3	1	8			

etc ....

Note:- (1) Blank Columns in Special Equipment Section mean - 0.

(2) This list was obtained from cards of the raid report card - No. 5.

APPENDIX No. 5

Form No. 14 (Page 2)

Date	Target	Group	Type	Mark	Special Equipment						Result	Sorties by equipment and result	Sorties by equipment
					Col. 41	Col. 42	Col. 43	Col. 44	Col. 45	Col. 46			
01 2	0202	8	4	6	5	0	5	0	0	0	1	2	2
01 2	0202	8	4	6	5	0	5	0	2	0	1	1	1
01 2	0202	8	4	6	5	0	6	0	0	0	1	1	1
01 2	0015	8	4	6	5	0	6	0	0	0	1	3	3
01 2	0015	8	4	6	5	0	6	0	2	1	1	1	1
01 2	0017	5	1	1	0	0	0	0	0	2	1	1	1
01 2	0017	5	1	1	0	0	0	0	0	2	1	23	23
01 2	0017	5	1	1	0	0	0	0	0	2	1	7	
01 2	0017	5	1	1	0	0	0	0	0	2	4	1	8
01 2	0017	5	1	3	0	0	0	0	0	1	1	1	1
01 2	0017	5	1	3	0	0	0	0	0	2	1	2	2
01 2	0017	5	1	3	0	0	0	0	0	9	1	13	13
01 2	0017	5	1	3	6	0	2	6	0	2	1	4	
01 2	0017	5	1	3	6	0	2	6	0	2	3	1	5
01 2	0230	8	4	0	0	1	1	0	0	0	1	3	3
01 2	0230	8	4	0	0	1	1	0	2	0	1	1	
01 2	0230	8	4	0	0	1	1	0	2	2	4	1	2
02 2	0210	8	4	0	0	1	1	0	0	0	1	1	1
02 2	0210	8	4	0	5	1	0	0	2	0	1	1	1

etc ....

Note:- This tabulation was obtained from cards of the Raid Report card - No. 4 type.