CHAPTER 15

RADIO ALTIMETERS

Aneroid altimeters used in aircraft in their most sensitive form gave very accurate readings of altitude when corrected for local atmospheric pressure, but suffered from the grave limitation that readings could be grossly inaccurate if the local atmospheric pressure was not known precisely. Many attempts had been made to obtain a direct measurement of the height of an aircraft above the ground. Development from 1920 to 1930 was chiefly centred on sonic altimeters, but the high noise-level in aircraft, and their increasing speed, made sonic methods impossible. Attention was turned to the use of radio, and as early as 1927 a frequency-modulating system was proposed. Research was mainly carried out in the United States of America and a radio altimeter based on that principle was demonstrated there by the manufacturers, the Western Electric Company, in 1938. Continuous electric waves were emitted, with rhythmic variations in frequency, from the underside of the aircraft. The reflected wave from the ground or water underneath was received in the aircraft and its frequency was compared electrically with the wave then being sent out. The longer the time-interval between the emission of the original wave and its reflection back to the aircraft, the more its frequency differed from that of the wave being emitted when it returned. The frequency difference was made to show the true terrain clearance directly on an instrument dial, and for small and medium distances, up to about 5,000 feet, the system worked fairly satisfactorily. The Standard Telephones and Cables Company became agents in the United Kingdom for the equipment, and in November 1939 supplied the Royal Aircraft Establishment with a model given the Service nomenclature of Radio Altimeter Type 1.

Development of Radio Altimeters Types 1 to 5

The altimeter was installed in a Bristol 142 aircraft, prototype of the Blenheim, and flight trials were begun in January 1940. It consisted essentially of a transmitter, receiver, power unit and aerial system, operating on a wavelength of 70 centimetres, and covered a single range of heights from 50 to 1,500 feet.[1] The aerial system consisted of two wide-band tuned dipoles mounted on a fairly flat section underneath the fuselage about 12 to 18 feet apart, end-on to each other, and connected through coaxial transmission lines;

[1] A.H.B./IIE/247. R.A.E. Paper, Radio/S.5204/BAS/14.

	Transmitter Unit	*Receiver Unit*	*Power Unit*
Dimensions in Inches.	9 × 6 × 21	9 × 6 × 21	9 × 6 × 21
Weight in Pounds.	15½	11	17
Detail.	Valve transmitter and modulator using Western Electric Company type of valve.	Diode mixer unit, L.F. amplifier, frequency counter, and meter operating circuit.	Total power consumption at 12 volts was 320 watts. H.T. provided by rotary converter.

one to the receiver and the other to the transmitter. During the trials accuracy was checked against a Kollsman aneroid altimeter and readings agreed within 10 per cent. On completion of the trials the equipment was rebuilt as an experimental frequency-modulated A.I. system and it was not further developed as an altimeter until October 1940 when a model was installed in a Bristol Botha aircraft. Mainly because of the necessity to use long aerial feeders the installation did not operate satisfactorily as an altimeter, and, with the co-operation of the Standard Telephones and Cables Company, the Royal Aircraft Establishment carried out extensive modifications which included the provision of two ranges, 0 to 500 feet and 0 to 5,000 feet. In January 1941 Headquarters Army Co-operation Command raised a requirement for the installation of a radio altimeter reading up to 10,000 feet in a Lysander aircraft which was to be used for calibration of the London anti-aircraft artillery barrage rangefinders. A suitably modified Type 1 was installed but proved to be no more satisfactory than the standard Kollsman aneroid and its use was abandoned. However, flight trials of the Botha installation were conducted in March 1941 when at heights between 150 and 8,000 feet accuracy within 10 per cent was obtained.[1]

Meanwhile, the advantages gained by Coastal Command with the installation in maritime aircraft of A.S.V. were to a great extent being nullified, especially during operations carried out at night, by the limitations of aneroid altimeters.[2] The degree of success achieved, particularly against U-boats, depended very much on the ability to conduct operations at optimum height of A.S.V. However, the atmospheric pressure at the operational area was often less than the pressure obtaining at base at the time of take-off, and if the drop in pressure had not been accurately forecast, the altimeter would indicate a height several hundred feet more than the actual true height of the aircraft above sea level, especially since reasonable calibration errors were bound to exist. Consequently, pilots were naturally apt to fly beneath cloud when the sky was overcast, disregarding the most effective height for A.S.V. performance, because they were unable to trust the altimeter readings sufficiently to descend through cloud to investigate an A.S.V. contact. Even if it were possible to preset altimeters to the correct local barometric pressure and to assume that calibration was accurate, the time-lag on readings during descent, coupled with changes of pressure within and around the cockpit at different speeds, made barometric altimeters unsuitable for such operations.[3] The provision of a direct-reading altimeter, accurate at low altitudes, was important for general A.S.V. reconnaissance purposes and essential for effective anti-U-boat operations carried out in darkness or in poor visibility, especially since the type of weapon in use limited successful attacks to heights between 120 and 500 feet.[4] In February 1941 a detailed specification for an altimeter which was independent of barometric pressure was formulated. It was to indicate, on a meter, heights from 20 to 2,000 feet, and no ambiguity was to occur below 500 feet. Weight

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[1] A.H.B./IIE/247.

[2] *See* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare'.

[3] In January 1943 the Royal Aircraft Establishment successfully completed a series of experiments with various types of maritime aircraft, in which static vent-holes were cut in hulls and fuselages at carefully selected points where pressure inside and outside was enabled to equalise at all speeds. (C.C. File S.7012/13.)

[4] Successful illumination of the target was not achieved until the introduction of the Leigh Light in June 1942.

of the equipment was to be reduced as much as possible, a target figure being 30 pounds exclusive of power supply but including the rotary transformer, which was to be capable of working with a 24-volt battery liable to vary from 21 to 29 volts during use. Power consumption was to be reduced to a minimum, a target figure being 100 watts.[1]

By April 1941 a Radio Altimeter Type 1, modified to indicate heights from 0 to 1,200 feet, had been installed in a Sunderland aircraft. Ground tests were considered to be satisfactory, but flight trials were a failure because the load placed on the aircraft power supply was too heavy. During May 1941 various methods of overcoming the defect were discussed by the Royal Aircraft Establishment, the Standard Telephones and Cables Company, and the aircraft manufacturers. It was eventually decided to provide a separate power supply for the altimeter. In the following month, by which time the operational requirement had become urgent, five altimeters were sent to the aircraft factory for installation on the production lines and ten to No. 10 R.A.A.F. Squadron at Pembroke Dock for installation under squadron arrangements. The aircraft fitted by the firm of Short Brothers were allocated to No. 201 Squadron at Lough Erne, and five aircraft were equipped by No. 10 Squadron. At the end of 1941 nine Radio Altimeters Type 1 were in operational use; one fitted aircraft of No. 10 Squadron had been lost. The majority worked satisfactorily for short periods only. Their unreliability was mainly due to faulty components and the short working life of the transmitting valves was a permanent source of trouble, whilst a shortage of test equipment increased the difficulties of servicing. Altogether 24 were delivered to the United Kingdom by the Western Electric Company, all manufactured in 1938 and 1939, and four were still in operational use in October 1943.[2]

At about the same time that Headquarters Coastal Command officially stated an operational requirement and produced a detailed specification, the Standard Telephones and Cables Company had begun, as a private venture, investigating the possibility of manufacturing a light-weight radio altimeter of smaller range than the Type 1. A development contract for seven equipments was placed with the firm in February 1941, and the first two experimental models were sent to R.A.F. Pembroke Dock in April 1941. The equipment, eventually known as Radio Altimeter Type 2, comprised two units, one containing the transmitter, receiver, LF amplifier and counter circuits, and the other the power unit. The aerial system was similar to that designed by the Western Electric Company. The altimeter was designed to give readings between 0 and 1,200 feet, and it was estimated that an RF output of 0·25 watts would be adequate, enabling a triode valve type RL.18 to be used as an oscillator. The modulating motor was a modified 24-volt DC camera motor, and a direct feed was used from the transmitter to the mixer stage, which was a balanced diode circuit designed to eliminate amplitude modulation as much as possible. The beat frequency between transmitted and received signals was, after rectification, fed to the frequency counting circuit, which actuated the indicating meter. The LF amplifier and frequency counting circuits were the same as those of Radio Altimeter Type 1, and the Western Electric Company indicating meter, calibrated from 0 to 1,200 feet, was also used.[3]

[1] M.A.P. File SB.8740. [2] A.H.B./IIE/247. [3] A.H.B./IIE/247.

All seven development models differed in detail, and considerable trouble was experienced in keeping them serviceable, mainly because of their many mechanical defects. Set No. 1 could not be made to work satisfactorily in spite of experimental improvements and was returned from Pembroke Dock to the manufacturers for further modification. In August 1941 it was again sent to R.A.F. Pembroke Dock for extended flight trials. Set No. 2, after the incorporation of similar modifications, was given flight trials at the Coastal Command Development Unit in June and July 1941. Set No. 3 was delivered to Gosport late in August 1941 only to be returned to the makers for modification because it could not be made to function. During September it was sent back to Gosport where, at the end of November 1941, it was considered that, although the altimeter contained inaccuracies, if known errors could be eliminated it would be satisfactory for torpedo-dropping operations. Set No. 4 was received by the Royal Aircraft Establishment in September 1941 and, after one month had been spent in making it serviceable, was installed in a Whitley aircraft, the aerials being mounted at a distance of four feet six inches from each other below the starboard mainplane outboard of the engine nacelle. During flight trials the indicated heights were compared with those obtained by means of photographing a ground pattern. Measurement of the pattern, the focal length of the lens, and the photograph, enabled heights to be quite accurately calculated. In November 1941 the establishment reported the radio altimeter to be reasonably accurate. Set No. 5 was sent to R.A.F. Wyton in September 1941 but never operated satisfactorily because of a faulty transmitter and set No. 6, sent to R.A.F. Bircham Newton in November, was never fully tested because height indications were unsteady; it was however put into use in December but the aircraft was lost on operations. Set No. 7 was sent to Heston in December 1941.

Naturally, in view of the way in which the development models had been distributed and because they were all different in varying degrees, it was not possible to locate and eliminate all their faults, and type approval could not be given to any one model in particular. All that was learnt was that whenever the altimeters did work they went near to fulfilling the specifications laid down, and no production order could be given although Headquarters Coastal Command, in urgent need, recommended production in quantity.[1] However, the manufacturers were sufficiently encouraged to begin making, during the summer of 1941, at their own risk, an additional 40 sets.[2]

Meanwhile the firm of E.M.I. had evolved an altimeter, weighing 75 pounds and consuming about 40 watts, in which interference by ground or sea surfaces with the electrostatic field of a condenser located on the underside of an aircraft gave an indication of height from zero up to a height equivalent to double the wing span of an aircraft. Although such a range was inadequate for maritime reconnaissance aircraft, the altimeter, ultimately known as Radio Altimeter Type 5, showed promise as a direct aid for blind landing, and the possibility that it might make development of a glide path system unnecessary was suggested. Prototypes were given Service trials in May 1941, when accurate height readings were obtained in a Whitley between 0 and 60 feet and in a Wellington between 0 and 120 feet. Type approval was given and by August 1941 an additional 25 development models were being manufactured. At

[1] Coastal Command File CC/S.18401.

[2] T.R.E. File 4/7/23 Part II.

the same time the Telecommunications Research Establishment had begun development of Radio Altimeter Type 4, based on the same principle used in Types 1 and 2 but working on a wavelength of 12·5 centimetres. It weighed about 50 pounds complete with generator and its power consumption was about 100 watts. The altimeter itself was designed to be contained in one standard box measuring 9 by 18 inches, whilst the power supply unit, which could, if required, be the same as that used for Type 2, was housed in a second container. The establishment considered it was essential that power should be supplied from a battery because, when the altimeter was used for blind landing, the engine speed was likely to be too low for satisfactory operation of an engine-driven generator. Since no other valve which could act as a replacement had yet been made, the use of the Standard Telephones and Cables Company valve Type S22A was planned, but modification would be necessary if large-scale production were required. The aerial system envisaged was two six-inch diameter paraboloid mirrors located side by side flush with the aircraft skin, or small Yagis. Two ranges of height were available on the indicator, 0 to 200 feet and 0 to 2,000 feet.

On 26 September 1941 a conference was held at the Air Ministry to discuss the performance of various types of radio altimeter and the possibilities of introduction into Service use. No definite policy had been stated and the Air Staff could not make a decision until the technical aspects and results of trials had been fully considered.[1] There were two main operational requirements; altimeters for specific tactical purposes and altimeters for blind landing. Obviously it would be desirable to produce one instrument to meet both needs and the implications were studied. Blind-landing trials had been carried out with both Type 2 and Type 5. The latter began giving indications of height at approximately 160 feet, and was reliable from 120 feet downwards, whilst with the Type 2 it was reasonable to expect indications down to 25 feet. The conclusions drawn from experience obtained during the trials were that it was necessary for an altimeter to give reliable indications from 100 feet down to a minimum of 5 feet, and that the ideal form of indication was a combination of a sensitive aneroid and a radio altimeter in which the latter indicated 90 feet at the same point as the aneroid indicated 9, with similar comparative indications at lower altitudes. Headquarters Coastal Command enumerated four different requirements for radio altimeters for operations at night against U-boats:—

(*a*) 60 to 1,000 feet for dropping bombs.

(*b*) 50 to 180 feet for dropping depth charges.

(*c*) 50 to 150 feet for dropping torpedoes.

(*d*) 500 to 1,200 feet, and if possible somewhat higher, for Toraplane attack.[2]

The need of Bomber Command was primarily an altimeter suitable for blind landing, but secondary requirements were one suitable for use during mine-laying operations and one which indicated heights from 10,000 feet up to the operational ceiling of bomber aircraft. Fleet Air Arm requirements were similar

[1] A.H.B./IIH/241/3/209. Radio Altimeters, Operational Aspect.

[2] A.H.B./IIH/241/3/209. The Toraplane was a naval 18-inch torpedo, fitted with stub wings and tail fins, which on release glided towards the target in the air, and on entry into water behaved like a normal torpedo. For further details *see* A.H.B. Narrative, 'The R.A.F. in Maritime War'.

to those of Coastal Command but also included specifications for minelaying, minesweeping, and blind landing. Height indications were required from 20 to 1,200 feet with two scales, one from 20 to 200 feet and one from 1,000 to 1,200 feet with 'hold-off' at 2,200 feet.[1] It was of paramount importance that size and weight should be reduced to a minimum. At the time there was no demand for radio altimeters in Fighter Command, and it was not until May 1943 that an official requirement was raised for an installation to be made in Beaufighter night-fighter aircraft in order to exploit to the greatest possible extent the advantages conferred by centimetric A.I. for interceptions at low altitudes over the sea.[2] Then American altimeters AYD and AYF were being introduced into the Service.

The meeting agreed that Radio Altimeter Type 5 was suitable for blind-landing purposes when fitted in aircraft of the same size as, or larger than, the Wellington, but would not be satisfactory for smaller aircraft because the maximum height indications would be inadequate. However, no other altimeter with the required performance was in a sufficiently advanced stage of development, and the need was urgent, especially since it was very important that pilots of operational bomber aircraft should be able to make blind landings during the winter months. With the expansion of the bomber force the problem of landing large numbers of aircraft was likely to become acute. In addition to the inherent difficulties of controlling large concentrations of aircraft, the emergencies likely to be created by bad weather and enemy intruder aircraft had to be borne in mind, and it was possible that completely blind landings might become the general rule. Consequently, recommendations for the accelerated production of Type 5 were made, although work on the development of an effective glide path indicator was to be continued in order that comparative trials might be held.[3]

Headquarters Coastal Command stated that Radio Altimeter Type 2 met the requirement of maritime aircraft, but expressed a preference for the indicator scales specified for the Fleet Air Arm. A contract was placed with the Standard Telephones and Cables Company for the 40 models which the firm had already started making by hand in its model-shop, which had only a limited output capacity. The drawings which had been completed made it possible, however, for the firm to pass manufacturing information to other contractors if and when required. At the best of times model-shop production was not very effective but difficulties were increased by an inability to obtain an adequate supply of the special small Pullins camera motors and Mortley Sprague rotary converters, and it was essential that there should be complete agreement on the design of such components before quantity production could be established. The Mullard RL18 valve was difficult to manufacture, and the other two types of valve used could be obtained only from the United States of America.

[1] When an aircraft climbed above the height which was the maximum indicated on the meter of a radio altimeter, the indicating needle stayed hard over against the stop at the top of the scale until, as the aircraft continued to climb, it reached an altitude where the needle began to fall back on the scale. The point at which it occurred was known as the 'hold-off' height, and was the point at which the wave reflected from the ground became so weak that it failed to operate the receiver. Hence 'hold-off' was an indication of the 'strength' of the transmitter and receiver and gave a margin of readings which measured the ability of a given installation to cope with varying sets.

[2] A.M. File CS.19991. *See* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception', for details of A.I.

[3] A.H.B./IIH/241/3/209.

Although the altimeter circuits appeared to be satisfactory, mechanical defects, faults in the aerial feeder system, and the question of the provision of test equipment had to be cleared. The first model was delivered on 17 February 1942 to the Royal Aircraft Establishment, where it was closely examined and tested. As a result, a number of modifications were agreed with the manufacturers. It was apparent that if the required accuracy was to be obtained in spite of the variations of supply voltage a carbon pile voltage regulator would be required. The voltage variation on all types of aircraft had presented a problem, to which no satisfactory solution had been found, for some years. Undoubtedly the introduction of carbon pile regulators with each piece of radio equipment in an aircraft eased the situation and overcame many of the difficulties but it was rapidly becoming essential to tackle the problem at its source, a project which had been on only very low priority at the Royal Aircraft Establishment for a long time. The Air Staff decided to give the task very high priority.[1] Arrangements were made for a representative of the Royal Aircraft Establishment to inspect every altimeter Type 2 before it left the contractor's factory, and provisional type approval was given on 28 February 1942.

Although further development was officially encouraged, production orders were limited because the intention was to use Type 2 only until Type 4 was ready for introduction in adequate quantity. The Air Staff requirement had been clarified to some extent. For Bomber Command the primary need was an effective blind-landing system; a requirement existed for both a glide path indicator and a radio altimeter. The glide path indicator was given the higher priority because preliminary trials had shown it to be the preferable method, but an altimeter reading down to 5 feet was acceptable as an interim measure. It was apparent, however, that radio altimeters would not be available for general use during the winter of 1941/1942, and Headquarters Bomber Command therefore officially requested that all heavy-bomber aircraft be provided with Type 5 during the winter 1942/1943, and stated that the lack of a suitable radio altimeter for Wellington aircraft would be accepted until Type 4 became available some time late in 1943. Radio Altimeter Type 5 was also made a requirement for torpedo-dropping aircraft based in the Middle East. For Coastal Command the primary and immediate requirement was for an altimeter reading from 50 to 1,500 feet, and a glide path system was a secondary need. Although Type 4 was considered to be preferable, Type 2 was acceptable in its existing form in view of the urgency of the requirement.[2]

A contract to develop Type 4 for production had been placed with the Standard Telephones and Cables Company in November 1941, and the firm thought that development would take at least one year, to which a period for tooling-up had to be added. It was considered that the best the same firm could do in delivery of Type 2 was 10 sets in June 1942, 15 in July and 20 in August and each month thereafter. If the altimeter was required in larger quantities for operational use until Type 4 was generally introduced it would be necessary to place orders quickly with additional contractors, since the development of a production prototype of Type 4 would be retarded if the firm was required to increase output of Type 2. In February 1942 the Air Ministry was advised by the Chief Technical Executive of the Ministry of

[1] A.M. File CS.15245.

[2] T.R.E. File 4/7/28.

Aircraft Production, Sir Frank Smith, to raise a requisition for 1,500 Type 2 altimeters, of which 200 were to be manufactured, by semi-tooled methods, at the Standard Telephones and Cables Company, 500 were to be obtained from the United States of America, and 800 from other contractors in the United Kingdom.[1] The British Air Commission was informed of the requirement for Radio Altimeters Type 2 and Type 4, and was given all the necessary technical data. Investigations were made of the possibility of manufacturing Type 5 in the United Kingdom at the rate of 300 per month.

The first delivery of Radio Altimeter Type 2 was made in June 1942 when eight were sent to the Coastal Command Development Unit for installation and flight trials in Wellington aircraft, and the production situation was then reviewed. 100 sets were being made by the Standard Telephones and Cables Company under model-shop production arrangements, and the output was expected to be 10 in October, 20 in November, and thereafter 20 per month until completion of the contract. An additional 100 sets were also to be made in the model-shops of Radio Transmission Equipment Limited, who expected to deliver 10 in November and 60 in December, a partially-tooled basis of production being employed. No contract had been placed in the United States of America; the remaining 1,300 were to be made up by 500 from the Standard Telephones and Cables Company, and 800 from Radio Transmission Equipment Limited, at the rate of 60 per month from January 1943 onwards. No further modifications were to be incorporated unless they were essential and did not delay production; since the total requirement was only 1,500, mass production methods were not practicable. Although the development contract for altimeters Type 4 had been placed over six months previously, no sets had been received from the makers, who were unable to promise that deliveries would begin before August 1942. The importance of ensuring rapid and adequate production in quantity of Type 4 before even considering the possibility of terminating contracts for either Type 2 or Type 5 was strongly emphasised. Because there were but few firms with the necessary laboratory and workshop facilities the development contract could not reasonably be transferred from the Standard Telephones and Cables Company, but plans were made for placing quantity production contracts elsewhere. Although originally the Air Staff was given to understand that output of altimeters Type 6 was expected to begin in or about March 1942, a production contract was not placed until June 1942, when an order for 8,000 sets was given to the Gramophone Company, who promised to begin delivery at the rate of 25 per week in November, rising to 250 per week by about April 1943. The delay made it necessary to hasten the proposed installation programmes by the provision of an additional supply of electrodes and transformers, so that aircraft could be modified whilst on the assembly lines, thus very much simplifying the task of installation when eventually the altimeters became available.[2]

Although the degree of efficiency of altimeters Type 2 was still an unknown quantity, as many as possible were required urgently for aircraft of Coastal Command, and in view of the importance of radio altimeters for anti-U-boat operations, priority of installation was decided as Leigh Light Wellingtons, Leigh Light Catalinas, other types of aircraft fitted with the Leigh Light, Sunderlands, Whitleys, and Catalinas. Of the first eight models received by

[1] T.R.E. File 4/7/23 Part II.

[2] A.M. File CS.15245.

the Coastal Command Development Unit only four could be made serviceable because of faulty and incorrect wiring. All four were inaccurate below 200 feet and were sent to the Royal Aircraft Establishment for modifications, mainly to the LF amplifier circuit. They were then returned to the development unit, and flight, as distinct from Service, trials, were concluded in mid-August 1942. Although on some particular flights performance of the altimeters was within acceptable tolerances, they were generally unreliable, largely owing to inferior mechanical design and workmanship. It was doubtful if any of the first 40 models would be satisfactory, and, at the suggestion of the Standard Telephones and Cables Company it was decided that, as work on them had progressed too far for further modifications, although known to be desirable, to be incorporated, the contract should be abandoned, and all modifications included in the remainder of the sets on order. The original design had continually been revised, and in order to achieve some degree of stabilisation it was agreed that the Royal Aircraft Establishment would try to give final type approval to 20 models which the firm intended to complete at the end of the year.

Five modified models were received by the Royal Aircraft Establishment in January 1943, and they were all unserviceable, a total of 35 different faults being discovered.[1] Four were eventually made serviceable and sent to the Coastal Command Development Unit for installation in Wellingtons. Three installations were completed, and flight trials were started, whilst main production was suspended at both manufacturers until tests of the first 20 models made by each had been fully and satisfactorily tested. Trials of the Standard Telephones and Cables Company models indicated that there was but little promise of an efficient altimeter Type 2 being produced within a reasonable time. It was clear that even more development was required before main production could be restarted. Although trials of the apparently superior Radio Transmission Equipment Limited version had not been completed, it was extremely doubtful whether the Royal Aircraft Establishment would be able to recommend the design for further production, and, with the advent of Type AYF, in July 1943 contracts for the manufacture of Radio Altimeters Type 2 were cancelled.[2]

The failure of the Type 2 altimeter project emphasised the vital need for an early stabilisation of design if rapid production in quantity was to be achieved. Many difficulties had been encountered by the manufacturers, and they had an adverse effect on the development of Radio Altimeter Type 4. There was a general shortage of skilled labour, and suitable training of unskilled labour took at least six months. Valve production presented a big problem. Many of the valves required for radio altimeters were difficult to make, and the capacity for valve production was, at the time, badly strained. The capacity of the valve industry in January 1941 for receiver type valves was about 11,800,000, and for other types of valve, about 280,000, per year.[3] By the end of 1941 it had been increased to 19,300,000 and 1,000,000. The extent of the expansion of the valve industry was indicated by the fact that new projects in connection with it approved in 1941 totalled in value about £2,450,000. Of that amount £45,000 had been allocated for receiver valve capacity, and the remainder for transmitter and special valves; no less than £1,500,000 for special valves alone. Only about £100,000 was spent on

[1] A.H.B./IIE/247. [2] A.M. File CS.15245. [3] T.R.E. File 4/7/23 Part II.

buildings, the rest being required for the provision and erection of plant. In the United Kingdom the valve companies designed and made the plant themselves, with the assistance of a few small firms. Difficulty was experienced in getting the companies to undertake such large expansion projects as they were mostly of the opinion that such undertakings were too much for them to handle. Plans had been made to obtain half the required plant from the United States of America, but that country's entry into the war deferred realisation of the plans for some time, and made it impracticable for either the required valves or the complete equipments to be manufactured there.

By June 1942 over one thousand production drawings had been completed for the Type 4 altimeter, and the design of the main production prototype was nearing completion. In view of the many difficulties, including that of finding a manufacturing firm able to accept a production contract, a decision on the production of Type 4 in quantity was deferred until completion of the trials of Type 2 in July and August 1942. By then, of the 24 development models being made, one was ready for flight trials, but no power unit was available. Workmanship had been improved and the results of ground tests were promising, and at the end of August 1942 two models were sent to the Royal Aircraft Establishment. Arrangements had been made that trials should be conducted with the first 12 models whilst changes, resulting in simplification and standardisation, should be incorporated in the second 12 models, which were to be prototypes for mass production.[1] Results of the flight tests undertaken at the Royal Aircraft Establishment quickly showed that the altimeters were unsatisfactory. There was considerable needle fluctuation, especially above 1,000 feet, and the models were unreliable below 150 feet when the 0 to 1,500 feet scale was used, although they were accurate down to 5 feet when the 0 to 150 feet scale was in use. Obviously immediate production was out of the question although further research and development were thought to be justified. The Standard Telephones and Cables Company was instructed to suspend temporarily further work on the Type 4 altimeter project in order that more effort might be concentrated on the production of a satisfactory Radio Altimeter Type 2. The firm delivered three assembled but unwired models to the Telecommunications Research Establishment where they were completed for installation by the Coastal Command Development Unit in Wellingtons for Service trials. Two installations rapidly became unserviceable, but with the third accurate readings were obtained on the low range, as had been found at the Royal Aircraft Establishment. On the high range readings were accurate up to 500 feet after which performance deteriorated, and the set was returned to the Telecommunications Research Establishment for further development. By March 1943 reasonably good results were being obtained, and arrangements were made for trials to be carried out by the Telecommunications Flying Unit who, in April 1943, reported very favourably on the results. However, delivery of altimeters from the United States of America had begun and the Air Ministry decided that production in quantity of Type 4 altimeters was no longer a requirement; development was to be completed, but on low priority, as an insurance against failure of the American instruments.

Meanwhile unexpected difficulties had been encountered with the introduction into the Service of Radio Altimeter Type 5. In July 1942 the Royal Aircraft

[1] A.M. File CS.18245.

Establishment began experiments to determine whether Monica and radio altimeters could be installed together in an aircraft. It was found that the close proximity of the Type 5 altimeter electrode caused the Monica radiation pattern to be distorted, and in order to eliminate the interference it would be necessary to modify considerably the electrodes and connectors of the altimeters, thereby delaying production by some months. In view of the successful development and use of glide path indicators, and the weight and drag factors imposed by the installation of radio altimeters, the operational requirement for heavy bombers was cancelled in May 1943. 850 sets, enough to meet the immediate needs in the Middle East, had been delivered from the contractors by March, and it had been agreed that production should be maintained at a reduced rate of 100 per month to continue the installation programme for Wellingtons allotted to the Middle East Command. However, production at such a rate proved to be an impracticable proposition, so in May 1943 it was decided that a higher rate should be maintained until 1,750 sets had been delivered, and the requirement for the outstanding balance of the order for 8,000 was cancelled.[1]

To meet the requirements of the Fleet Air Arm, the Standard Telephones and Cables Company was asked in November 1941 to develop a light-weight version of Radio Altimeter Type 2. Two designs were completed and a prototype of each was delivered to the Royal Aircraft Establishment in March 1942 for type approval tests. Because they were mechanically unsound they were rejected. The contractors submitted modified models in September 1942, when flight tests were satisfactory. As a result the Royal Aircraft Establishment and the manufacturers together evolved a design which became known as Radio Altimeter Type 3, and in which it was hoped to overcome the defects of Type 2. In October 1942 a development contract for 12 models was placed with the firm, and delivery to the Royal Aircraft Establishment began in June 1943. Two were installed in Albacore aircraft for trials at the Telecommunications Flying Unit and one in a Wellington for trials at the Coastal Command Development Unit. Reports from the Royal Aircraft Establishment indicated that the altimeters were superior in reliability and workmanship to the Type 2, and they appeared to be accurate. However, before any decision to arrange production was made, considerably more detailed information was required. Experience had shown that not only were thorough Service trials a necessity, but also a thorough assessment of the suitability of the instruments for quantity production methods. Reports of the Service trials, which were continued by the Fleet Air Arm as well as the Royal Air Force until October 1943, were encouraging, but as the Type 3 altimeter was not outstandingly superior to the altimeters being received from the United States of America, production in quantity was not ordered.

Research and development of radio altimeters based on pulse and frequency change principles had continuously been pursued in the United States of America, especially in the laboratories of the Radio Corporation of America, and the progress achieved was carefully studied by the British Air Commission, which was kept fully informed of the operational requirements of the Royal Air Force and the Fleet Air Arm. Orders were placed for development models of the R.C.A. altimeters in November 1941, and in the summer of 1942 the British Air Commission approached the Munitions Assignment Board for an allocation

[1] A.M. File CS.15245.

of AYD and AYF altimeters. The knowledge and experience gained during the processes of development and trials in the United Kingdom were utilised when the British Air Commission, through the Joint Radio Board, formulated a common requirement and specification acceptable to all the Services of both countries.

Procurement and Trials of AYB, AYD and AYF Altimeters

An experimental model of the R.C.A. altimeter, known as Type AYB, was flight-tested successfully in the U.S.A. on 17 November 1941. The first engineered version of the AYB altimeter was lent to the British Air Commission by the United States Navy, who were convinced of the paramount importance of the operational requirement for a radio altimeter to be used in conjunction with A.S.V. and the Leigh Light, and was taken to the United Kingdom in September 1942 by Dr. A. G. Touch. Within one week the altimeter had successfully passed all the tests imposed by the R.A.E. It provided satisfactory readings between about 15 and 400 feet, its power consumption was low, and its weight, including cabling, was only 26 pounds. The B.A.C. was instructed to arrange for an allocation from production, and by April 1943 nearly 350 had been delivered to Fort Worth for installation in Liberators, and 12 to the United Kingdom. Meanwhile, an important engineering aspect of altimeter installation had been settled. It was the practice in the U.S.A. to earth the negative side of the battery in the aircraft, whilst in the United Kingdom a system of twin wires, both insulated from the airframe, was employed. When, initially, AYB and AYD altimeters were accepted for installation in American aircraft the difference did not matter, but when installation in British aircraft was projected, an agreement became necessary, and eventually the Ministry of Aircraft Production accepted the American principle, which was still standard British practice at the end of the war.[1] Production of AYD was estimated as 300 in April, 400 in May, and 500 in June 1943, when delivery to the United Kingdom was expected to begin. In March 1943 a hand-made model of AYF was sent to the United Kingdom. It provided readings between 0 and 400 feet and 0 and 4,000 feet, operated on a frequency of 420 megacycles per second, contained a limit height indicator, was suitable for controlling an automatic pilot, and weighed about 25 pounds. A production model was tested at the R.A.E. in November 1943, and several recommendations for modification were made, including reduction of the maximum height indication to 2,000 feet, a change of modulation frequency from 120 to 80 cycles on switching from low range to high range, and reduction of the transmitter coupling so that half of the available transmitter power was fed into the aerial. It was considered that incorporation of the modifications would considerably reduce errors.

By November 1943 the R.A.E. had completed flight tests of trial installations of AYD in 18 types of aircraft; Wellington Marks XI and XII, Beaufighter, Fulmar, Barracuda, Swordfish, Albacore, Firefly, Lancaster, Halifax, Catalina, Sunderland, Mosquito, Hampden, Liberator and Hudson. At first the R.A.E. attempted to follow the installation methods recommended by the R.C.A. and the United States Navy, particularly for positioning of aerials, but results were unsatisfactory until aerials were mounted on the tailplane, when performance was very satisfactory, error amounting to no more than 5 per cent over the

[1] AYD was a production version of AYB modified so that it was suitable for controlling an automatic pilot.

whole range.[1] The great advantage of the tail installation lay in the fact that there was no possible source of spurious coupling between aerials caused by reflection from the airframe.

By January 1944 400 AYD altimeters had been received in the United Kingdom, but by the end of April 1944 the manufacture and supply of AYD had ceased, and in the following month it was decided that, as stocks of AYD were inadequate to meet existing R.A.F. requirements, AYF altimeters were to be installed, for use on low range only, in all types of aircraft other than the Wellington, for which the stocks of AYD were reserved.[2] AYD and AYF both consisted of transmitter/receiver, aerial, limit switch, and connector units, and altitude indicator unit. The aerial, limit switch, and connector units were interchangeable both physically and electrically, and the transmitter/receiver units were interchangeable physically. The altitude indicator units were not physically interchangeable because the methods of mounting were different, but an AYD meter could be used with an AYF transmitter/receiver, and an AYF meter with an AYD transmitter/receiver, to give satisfactory results over the 0 to 400 feet range. An Air Staff requirement was stated for installation of radio altimeters in all general reconnaissance, fighter reconnaissance, torpedo-bomber, air/sea rescue and meteorological aircraft of Coastal Command; in Mosquito night-fighter aircraft of A.D.G.B. and A.E.A.F.; in night-fighter aircraft equipped with centimetric radar, and torpedo-bomber, rocket projectile and Leigh Light-equipped aircraft of the Mediterranean Allied Air Force; aircraft of Flying Training Command; and five squadrons of Transport Command.[3] Future requirements were anticipated to be installations in intruder aircraft of A.E.A.F. and Bomber Command, and in all maritime aircraft based in A.C.S.E.A. and West Africa.

Because of technical difficulties an AYF installation programme was not begun until July 1944 and was further delayed by the absence of test gear, production of which fell seriously behind schedule. The lack of test gear not only caused delay, but prevented the use of completed installations. In September 1944 the R.A.E. completed trials of 74 installations. Results indicated that, given correct operating conditions, normal maximum errors would fall within limits of plus or minus 60 feet plus or minus 10 per cent above 1,000 feet, and plus or minus 60 feet plus 37 per cent and minus 10 feet below 1,000 feet, on the high range, and plus or minus 6 feet plus or minus 10 per cent above 50 feet on the low range.[4] It was therefore decided that when AYF replaced an AYD installation only the low range was to be used and slight modifications were introduced to prevent use of the high range and to bring its performance into line with that of AYD. Both AYD and AYF provided inaccurate readings below 50 feet and consequently their use for landings was dangerous, and the high range of AYF was considered to be unsafe. Main force aircraft of Bomber Command were not therefore included in the installation programme, which was restricted to special duty and maritime reconnaissance aircraft, and to night fighters to facilitate interceptions over the sea at low altitude. In December 1944 the R.A.E. experimented with AYF to ascertain whether it could be safely used from 1,000 to 4,000 feet, and subsequently considered that, with aerials spaced 10 feet apart it could be safely used by maritime reconnaissance and night-fighter aircraft, but only when over the sea.

[1] A.M. File CS.19648.
[2] A.M. File CS.21402.
[3] The remainder of aircraft used by Transport Command were equipped with altimeters in the U.S.A.
[4] A.M. File CS.22905.

Consequently, when permission was requested to install AYF in pathfinder aircraft of M.A.A.F., it was granted only with the limiting conditions that the altimeter readings were to be used solely when aircraft broke through cloud over areas of sea, and never over land.

Installation of AYD and AYF in R.A.F. Aircraft

An AYD installation programme for Wellingtons of Coastal Command was begun in July 1943 by five fitting parties of No. 26 Group, a start being made with Nos. 172, 407 and 612 Squadrons.[1] By the end of March 1944 retrospective fitting in those squadrons and Wellingtons of Nos. 179 and 304 Squadrons, Beaufighters of Nos. 144 and 254 Squadrons, and Halifaxes of Nos. 518 and 520 Squadrons, had been completed, whilst the Liberators of Nos. 53, 59, 120, 224, 311 and 547 Squadrons had been equipped in the U.S.A. Progress was being made with installations, on high priority, in Catalinas of No. 210 Squadron, Halifaxes of Nos. 58, 502 and 517 Squadrons, and Sunderlands of Nos. 10, 228 and 461 Squadrons, and a programme on low priority for 19 other squadrons, and for operational training units, was planned.[2] However, the operations to be undertaken for the projected liberation of Europe necessitated the provision of radio altimeters in all aircraft of Coastal Command, and every endeavour was made to introduce aircraft production-line installation as rapidly as possible, and the number of fitting parties was increased.[3]

Until April 1943 there was no requirement for the provision of radio altimeters in fighter aircraft, but then a requirement for a trial installation of Radio Altimeter Type 4 in a Beaufighter night-fighter aircraft was stated in order that the possibility of extending even further the advantages conferred by centimetric A.I. for low-altitude interceptions over the sea might be investigated. Great difficulty was being experienced in intercepting enemy aircraft engaged on minelaying and maritime reconnaissance duties at night because they were operating at very low heights, and the standard barometric altimeters were unsuitable for safe use below 100 feet. As it had been decided not to proceed with the production of Type 4 altimeters, and in view of the fact that Coastal Command Beaufighters were able to operate safely down to within 50 feet of the sea when equipped with AYD, trial installations of AYD in night-fighter aircraft were arranged. Headquarters Fighter Command stressed that an assessment of the merits of the radio altimeter as such was not required; the object of the trials was the determination of its value as an aid to successful interception. Preliminary trials of an AYD installation in a Mosquito XII were carried out by crews of the Fighter Interception Unit, who used it for operational patrols. They considered that the radio altimeter was a valuable addition to the equipment of night-fighter aircraft; it gave pilots the necessary confidence to dive to and fly at low altitudes over the sea at night for the interception of minelaying aircraft and for intruder sorties.[4] In August 1943, therefore, Headquarters Fighter Command requested that thorough Service

[1] A.M. File CS.19648. Headquarters No. 43 Group assumed responsibility for retrospective installation in aircraft of Coastal Command in June 1944. (A.M. File C.16146/44.)

[2] A.M. File CS.21403.

[3] In addition to the comprehensive fitting of Coastal Command aircraft, in April 1945 AYF and AYD altimeters were in use in many aircraft of other commands, including over 100 Mosquitos of the Tactical Air Force, over 200 Mosquitos of Fighter Command, over 350 Dakotas and 350 Liberators of A.C.S.E.A., about 50 Mosquitos, 150 Liberators and 15 Wellingtons of M.A.A.F., about 180 Mosquitos and 20 Lancasters of Bomber Command, and about 50 Wellingtons and 40 Liberators of R.A.F. Middle East.

[4] F.I.U. Report No. 213.

trials of AYD and AYF should be arranged; it was not then possible to express a precise operational requirement, but installation of AYD or AYF in six night-fighter and six intruder Mosquito aircraft was suggested. A prototype trial installation was made by the R.A.E., during the process of which several technical problems were encountered, chief among them being the need to remove some other equipment in order that adequate space might be provided. Eventually it was decided that the rate-of-climb indicator should be removed, and successful flight tests of the installation were made in December 1943. Operational trials were continued during the first few months of 1944, and as a result Headquarters Air Defence of Great Britain stated an operational requirement for the installation of AYD, in its existing form, in all night-fighter aircraft likely to be engaged on low flying over the sea at night. Its provision in intruders was not a requirement since it did not fulfil the need for accurate readings between 0 and 4,000 feet; intruder aircraft did not always approach enemy coastline at low altitude but were often forced by bad weather to fly at above 10,000 feet until the target area was reached, when height had to be lost rapidly.[1]

When the role of night-fighter aircraft in the Normandy operations was planned it was decided that one of the major problems likely to be met in the defence at night of shipping in the operational area would be the interception of torpedo-bombers at very low altitudes. It was known that anti-shipping aircraft of the *Luftwaffe* were equipped with an efficient radio altimeter which enabled pilots to fly with confidence as low as 50 feet above the sea even in complete darkness. Dependence on aneroid altimeters in similar conditions was believed to have been the cause of many casualties in the R.A.F., and of many failures to destroy enemy aircraft. In view of the shortage of supplies and the installation priority accorded aircraft of Coastal Command and the Fleet Air Arm, it was decided that one squadron, No. 604, of Mosquito XIII aircraft should be equipped as an urgent requirement and should be given special training in low-level interceptions. Arrangements were made for a special fitting programme, and by 7 May 1944 the first installation had been completed; the operational requirement was increased to installations in nine night-fighter squadrons.

In July 1943 it was agreed that a radio altimeter providing accurate readings between 0 and 600 feet was a requirement for aircraft used for dropping paratroopers, and the possibility of modifying AYF so that the 0 to 400 feet range was extended to provide accurate readings at 600 feet was considered. The Air Ministry was disinclined to authorise such a modification unless it was operationally essential and proposed that trials should be conducted with AYD. However, in the following month it was reported that the modification entailed to make AYF provide readings from 0 to 800 feet was negligible, consisting mainly of a readjustment of the frequency sweep during the process of lining-up; similar modification of AYD was not feasible because, although the range was increased, the hold-off height was comparable with the maximum reading. The possibility of effectively modifying AYF was investigated by the R.A.E., the only model in the United Kingdom, the R.C.A. experimental version, being used for the tests. Flight trials revealed that the altimeter could be made to function satisfactorily from 0 to 800 feet; a reasonable maximum error to be expected was plus or minus 5 per cent with additional errors of plus or minus

[1] A.M. File CS.19991.

12 feet. Considerable controversy regarding the practicability of modification ensued. The manufacturers could not be expected to upset the planned production programme in order to incorporate the change, and retrospective modification in the United Kingdom involved dismantling the equipment in order that the indicator dial might be repainted; a process which entailed recalibration. However, experiments revealed that retrospective modification was feasible, although if large numbers were involved the work would have to be carried out by a firm of instrument makers rather than by unit personnel. In January 1944 flight trials of a modified AYF installation in an Albemarle aircraft were considered to be satisfactory, and Headquarters Transport Command stated a requirement for the installation of suitably modified altimeters in 150 Dakota aircraft. In April 1945 270 Dakotas in service with Transport Command were equipped with modified AYF and 50 Stirlings with modified AYD.

Specifications for British Altimeters, 1944

Specifications for British altimeters to be developed in the United Kingdom, based on the experience gained with AYD and AYF, were discussed at the Air Ministry on 23 August 1944.[1] AYD and AYF altimeters provided facilities otherwise unobtainable but would not meet future requirements, and complete dependence on development and production in the U.S.A. was undesirable. Specifications were formulated for two types of altimeter, one, employing frequency modulation, for use up to 5,000 feet, and another, employing pulse modulation, for use from 800 to 50,000 feet. The first was required for installation in aircraft engaged on low-level bombing, torpedo and rocket projectile attacks, parachute dropping, mine-laying, night fighting, and routine flights in poor visibility. Two ranges were required, 0 to 1,000 and 0 to 5,000 feet, with a maximum fixed error of plus or minus 3 feet and maximum additional general error of plus or minus 2 per cent on the low scale, and a maximum fixed error of plus or minus 15 feet and maximum additional general error of plus or minus 15 per cent on the high scale. Indication was to be provided on a single meter inscribed with graduations increasing in separation towards the lower end of the scale. The installation was to include an optical warning system by means of which a pilot would be able to preselect a critical height and be informed, by a simple light code, when he was just above, just below, or precisely at that height. Weight was not to exceed 20 pounds. The second altimeter was required for installation in aircraft engaged on high-level and high dive-bombing, meteorological flights, photography, and night fighting, and for navigation generally. The range required was from 80 to 50,000 feet, with a maximum error of plus or minus 30 per cent, and stability within plus or minus 30 feet over a period of 10 minutes. Indication was to be provided on a cathode ray tube. A critical height indicator, auxiliary to the main equipment and detachable if not wanted, was to be provided for use in high dive-bombing operations. Weight was not to exceed 35 pounds. Both altimeters were to be interchangeable to the maximum extent possible.[2]

[1] A.M. File CS.22904.

[2] Flight trials were carried out at the R.A.E. in November 1943 of another radio altimeter developed in the U.S.A., SCR.718. It was designed to provide readings between 300 and 40,000 feet with a maximum error of plus or minus 80 feet plus or minus ½ per cent. The transmitter and superheterodyne receiver were housed in one container, operated on 440 megacycles per second, and weighed about 9½ pounds. Indications were presented on a cathode ray oscilloscope with a circular time-base, the unit weighing about 10 pounds; total weight of the installation was about 35 pounds. (A.M. File CS.21403.)

CHAPTER 16

STANDARD BEAM APPROACH, RADIO TRACK GUIDES AND V.H.F. BEAM APPROACH

The earliest experiments in blind landing were carried out in the U.S.A. in 1929 when a demonstration of a completely hooded flight, from take-off to landing, was given. A beam system was used and further development was undertaken in the U.S.A. by the Bureau of Standards. The radio equipment operated on frequencies of 200 to 400 kilocycles per second, which were reserved in the U.S.A. for air navigation radio. In Europe, however, those frequencies were utilised for broadcast stations, and when experimental work was begun in Germany frequencies of 30 megacycles per second and above were employed. The German system was installed at Tempelhof airport and was demonstrated to British representatives of the Royal Aircraft Establishment and civil aviation. The *Lorenz* Company invested a considerable amount of money in development and the system was eventually produced by them for commercial use. By 1936 it was being widely used by European civil airlines as an aid to blind landing. Meanwhile the Hegenberger system, in which a radio compass was used, was being developed in the U.S.A. During this period no research or development was being undertaken in the United Kingdom although a Fog Landing Panel at the R.A.E. received and studied reports of systems being developed abroad. In 1935 the Air Ministry made arrangements for experiments to be conducted at the R.A.E. with the Hegenberger system and purchased two sets of equipment. Before their installation was completed the Air Ministry accepted an offer made by the firm of Standard Telephones and Cables to provide, free of charge, a portable military version of the German equipment for trials.[1]

The *Lorenz* beacon blind-landing system consisted of both ground and aircraft radio equipment. The ground equipment comprised a main beacon transmitter and two smaller beacon transmitters. The main transmitter operated on about 33 megacycles per second to energise a special aerial system which laid down the necessary track. It was sited on the extreme edge of an airfield and projected an equi-signal zone of 4 degrees width across it to a range of approximately 20 miles at 1,500 feet. The aerial system of the main beacon could be lined up on any desired bearing, the one chosen being that which gave the minimum of obstructions along the centre of the beam. It was necessary to inform the pilot of the bearing before a landing was attempted. The two small auxiliary marker beacon transmitters and aerial systems were installed along the line of approach, the inner one usually being sited at the opposite end of the airfield from the main beacon and the outer one about 3,000 yards further out; they operated on 35 megacycles per second. The aircraft installation consisted of a receiver, weighing about 80 pounds, a fixed vertical aerial, and a marker beacon aerial.

[1] The firm was the agent in the United Kingdom for the *Lorenz* Company. Both were controlled by the International Telephone and Telegraph Company of New York. (A.M. File 445921/35.)

There were three phases in *Lorenz* approach procedure. In the first the aircraft was navigated, either by dead-reckoning or with the assistance of wireless direction-finding, to the vicinity of the beam, usually to a point about 15 miles from the airfield. Then the approach was begun. The pilot was given aural and visual indications of his position in relation to the centre of the beam no matter what his heading. Indication of his distance from the airfield was furnished by the marker beacons, the transmissions of which were radiated vertically and were received aurally or visually. Two neon lights, mounted on the instrument panel, glowed when the aircraft passed directly above the appropriate marker. When he was flying along the centre of the beam the pilot received a steady signal; when he was to port dots were received, and the reception of dashes indicated deviation to starboard. Also, visual indications were displayed on a meter, the pointer of which 'kicked' to port or starboard as the aircraft deviated from the beam, and remained stationary when the pilot was flying along the correct path. A glide path indicator was provided to give information of height, but proved to be inadequate unless approaches were being made over completely flat terrain.[1] The third phase was the actual touch-down.

Pre-war Development of *Lorenz* in the United Kingdom

Preliminary work was undertaken by the R.A.E. in the early months of 1936 for trials of the *Lorenz* equipment to be held in May. The airfield at Abingdon was chosen for them because that at Farnborough was considered to be unsuitable for the practice of blind approaches, and they were carried out simultaneously with trials of the Hegenberger system.[2] The aircraft used were twin-engined Monospar S.T.25, two of which were specially obtained for the trials. They were equipped with Sperry blind-flying instruments, sensitive Kollsman altimeters, and rate of ascent meters; all ignition and electrical services were fully bonded and screened. The trials were prolonged because delays had been caused through a series of technical troubles and faults in the tuning up and maintenance of the equipment; some difficulties were caused by lack of previous experience but others were attributable to faults in design. At one stage of the trials the aircraft equipped with *Lorenz* was flown to the civil airport at Heston so that approaches could be made there, and the pilot was accompanied by a representative of the firm of Standard Telephones and Cables. Approximately 30 approaches were made with *Lorenz*, of which eight in the early stages were failures, mainly due to lack of experience on the part of the pilot. On the whole the approaches were very successful and in about 70 per cent of flights the approach procedure ended in a successful landing, the pilot still being hooded.[3] At the end of July 1936 senior officers from the Air Ministry, Bomber, Fighter, Training and Coastal Commands inspected the Hegenberger and *Lorenz* systems and were given demonstrations of blind approach flying.

The *Lorenz* system contained certain disadvantages. It had not the homing property of the Hegenberger system, for pilots had to locate the beam in the first instance by other navigational means. Also, in the early development stages, no information was available of the direction in which an aircraft was heading other than that it was on the beam. The glide path indicator was

[1] A.H.B./IIE/228. Blind landing. [2] A.M. File 445921/35. [3] A.H.B./IIE/228.

definitely unreliable and further research and development were needed. The advantages of the system appeared to outweigh the disadvantages, a main one being that it could be introduced into the Royal Air Force quickly because it required very few alterations, and the chief one being its manufacture with British components. The Hegenberger system required considerable development to fit it for Service use and as it was an M.F. system the radio compass suffered from interference. A further advantage lay in the confidence likely to be produced by the *Lorenz* track system; pilots would know that, once they were on the beam, their approach path was free from obstructions. It was possible for them to land at the first approach, of great value when returning from operations, but, on the other hand, if they made bad approaches, they could, without undue strain, return for a second attempt. The fact that *Lorenz* operated on frequencies of 30 to 35 megacycles per second was of great importance because interference was experienced to a far less degree than on the frequencies used in the Hegenberger system. Thus, from both the technical and flying points of view, the *Lorenz* system was considered preferable. The technical officers from the R.A.E. and the pilot who flew the aircraft during trials of both systems were agreed on this. Considerable research and development was necessary, but it was practicable to use the equipment in its existing form. An important point was that the pilot regarded the equipment as an approach system only; completely blind landing was not feasible as a general rule though possible in certain cases.[1]

A recommendation that the Royal Air Force should be equipped with the *Lorenz* system was made at the third annual Direction Finding Conference on 27 November 1936, when it was proposed that 12 sets of ground apparatus and 80 aircraft installations should be purchased for Service trials in the various commands; the former were to be mobile so that trials could be held at different airfields.[2] *Lorenz* had been adopted by various European countries and as a result of trials held at Heston and Croydon in 1936 it was likely to be standard equipment for civil airlines in the United Kingdom, but Service trials were needed to find out whether it was suitable for use in the Royal Air Force.[3] In February 1937 the recommendation was approved by the Chief of the Air Staff.[4]

The need for blind approach and blind-landing systems in the Royal Air Force was urgent. To avoid delay it was decided that versions of the German equipment, similar to that used at Abingdon, should be produced by Standard Telephones and Cables, rather than that the firm should attempt to develop a new design based on the German one. *Lorenz* was an approach system only

[1] A.M. File 445921/35. The pilot was Flt. Lt. R. S. Blucke, R.A.F.

[2] £50,000 was provisionally included in the 1937/1938 Air Estimates to cover the cost of the proposal; £3,000 for each ground, and between £150 and £200 for each aircraft installation. The allocation of equipment was :—

	Ground	*Aircraft*
Bomber Command	3	36
Fighter Command	1	3
Training Command	2	6
Coastal Command	2	Enough to equip one flight of Ansons and one squadron of flying-boats.
Spare	4 (for future allocation)	

[3] By December 1937 three ground installations had been completed at Croydon, Heston and Gatwick. (A.H.B./IIE/228).

[4] A.M. File S.39487.

and could not be used for blind landing by the average pilot, but there was no time to await the development and production of a blind-landing system, and *Lorenz* was already in the production stage.[1] The R.A.E. was instructed to prepare specifications, embodying such improvements as had been devised during the experimental work done on the original *Lorenz* set lent to the Air Ministry the previous year.[2] Specifications of operational requirements for the *Lorenz* installation were also prepared. On 10 June 1937 a meeting was held between representatives of the Air Ministry, the R.A.E. and Standard Telephones and Cables to discuss production of *Lorenz* for Service trials. It was decided that the specification prepared by the R.A.E. should be widened to permit modification of the ground equipment to make it portable. British valves and mainly British components were to be used in construction, but in reply to a request from the radio firm, the Air Ministry gave permission for the use of German castings. During the late summer of 1937 the wisdom of the choice of *Lorenz* for Service use, which had already been doubted, was again questioned, and it was proposed that all radio firms already working on the research and development of a blind-landing system should be invited to submit designs. As the primary consideration was the need for speedy provision the decision to proceed with *Lorenz* was reaffirmed, rather than to risk further delay by waiting for a new and experimental system, and in August 1937 a development contract was placed with Standard Telephones and Cables.[3] *Lorenz* was to be used for Service trials; from information acquired at the trials, specifications were to be produced so that commercial firms might compete to evolve the best design.

In December 1937, after the commands had decided where the ground beacons were to be situated, the Air Ministry agreed to the R.A.E. allocation of frequencies, which were to be contained in the band 35·5 megacycles per second to 40·5 megacycles per second. Beacons operating on the same frequency were to be at least 60 miles apart; if they were any closer there was to be a frequency spacing of at least one megacycle per second. It was decided that there should be three different operating frequencies for the 12 transmitters; 36·25 megacycles per second, 39·25 megacycles per second and 40·25 megacycles per second.[4] In August 1938 the first two were changed to 36·4 megacycles per second and 39·4 megacycles per second. In October 1938 the frequency allocation was again changed because a six-channel receiver was substituted for the original three-channel receiver.[5]

In August 1937 Headquarters Bomber, Fighter, Coastal and Training Commands informed the Air Ministry at which stations the installation of *Lorenz* beacons, allocated under the initial contract, was required. In September and October of that year representatives from the R.A.E. visited the selected stations to find out whether the sites were suitable, and carried out tests, using the ground equipment and specially fitted aircraft employed for the Abingdon trials. By the beginning of 1938 the R.A.E. tests were completed and representatives from Standard Telephones and Cables then visited the sites to examine them. To assist them the representatives were provided with the R.A.E. siting reports and plans for the proposed beacon positions at each

[1] A.M. File S.39509. [2] A.M. File 625411/37.

[3] In June 1938 the contract for 12 ground installations was increased by one, and that for aircraft installations was increased from 80 to 82. (A.M. File S.39509.)

[4] A.M. File 625411/37. [5] A.M. File S.39509.

airfield. The firm submitted proposals for any alterations considered necessary and after that works services, such as power supply to the beacons, control lines from the Watch Office to the main and inner beacons, and the clearance of trees, shrubs, and other obstructions, became the responsibility of the Air Ministry Works Department. The General Post Office provided control lines from the Watch Office to the outer marker beacons. Progress was made with the initial works services throughout 1938 although the actual installation of ground transmitters did not begin until May 1939. It was arranged that an engineer from Standard Telephones and Cables should be present for about three weeks at R.A.F. stations where ground transmitters were to be set up in order to assist the local personnel in the operation and maintenance of the system.[1] As *Lorenz* was a new and rather complicated equipment the Air Ministry arranged that prototype installations in each type of aircraft in which it was to be fitted were made by the R.A.E. When they had been completed the installation programme was the responsibility of the aircraft contractors. Signals personnel of squadrons were instructed to glean as much information as possible on the operation and servicing of the sets while expert tuition was available. Until sufficient test oscillators were provided for use with the equipment, periodic inspection tests, similar to those devised for W/T sets, were to be held.[2]

The anticipated date of delivery of 12 ground and 80 aircraft equipments' May 1938, proved to be over-optimistic, and difficulties were encountered when attempts were made to install the equipment in bomber aircraft because of lack of space.[3] In April 1938 it was decided that all beacons, except one allocated to Coastal Command, were to be installed on a permanent instead of a transportable basis because it was difficult to monitor mobile beacons. The difficulty could be overcome for trials of comparatively short duration but was insurmountable in operational conditions and the contract was therefore amended. Throughout the second half of 1938 and the first of 1939 the R.A.F. policy on the subject of blind approach was gradually changing. The original plan for the design to be kept static until Service trials had been completed, in order to hasten introduction, was abandoned because of the slowness of production. In view of the slow progress made it was considered preferable to accept *Lorenz* as a standard beam approach system, without waiting until trials had been held and tenders accepted from radio firms for experimental equipment, and to incorporate suitable modifications.

In November 1938, attention was drawn to certain defects in the equipment, notably the unreliability of the glide path indicator used with it, and it was suggested that the use of horizontally-polarised waves might obviate them. Without satisfactory glide path indication it was not possible to convert a blind approach into a blind landing, and in February 1939 development of a suitable indicator was included in the Standard Telephones and Cables contract. The design and installation of *Lorenz*, the best means of developing it to meet future needs, and the relative merits of various blind-landing systems developed by radio firms in Europe and the U.S.A. were the subject of discussions at the Air Ministry. It was noted that a blind-approach system developed by the firm of Phillips was very efficient in that a good equi-signal zone was provided,

[1] A.M. File S.39509.
[2] Bomber Command File BC/20759 Pt. II.
[3] A.M. File S.39509.

but it was estimated that it would take at least one year to bring it to the same stage of production as *Lorenz* had reached. The immediate requirement of the R.A.F. was still to be met with *Lorenz*, and future development of blind-approach systems was to be entrusted to commercial radio engineering firms, with the R.A.E. acting in a supervisory capacity.[1] In May 1939, although Service trials of the *Lorenz* equipment ordered under the initial contract had not been held, a second contract, for 25 ground and 2,500 aircraft installations, was placed with Standard Telephones and Cables. Similar arrangements as with the first contract were made for a representative of the firm to visit sites selected by the Air Ministry to ascertain their suitability. Delivery of the first sets of ground equipment was expected at the end of that year.[2]

The position at the outbreak of war was that, of the 13 ground sets ordered for Service trials, nine had been installed and four more were in process of installation.[3] 73 aircraft equipments had been delivered and had been installed in Whitley, Wellington, Blenheim, Hampden, Battle, and Harrow aircraft of Bomber Command, as well as in four Gladiator aircraft of the Meteorological Flight at Mildenhall. Amongst the aircraft awaiting fitting at the contractors were Manchesters, Stirlings, Halifaxes, and Ansons.[4]

Training in the servicing and operation of *Lorenz* was given to signals personnel at airfields and at manufacturers by Standard Telephones and Cables representatives in 1938 and 1939. By the outbreak of war the subject had been introduced into the syllabus of wireless electrical mechanic apprentices of No. 1 Electrical and Wireless School.[5] In the autumn of 1939 the Blind Approach Training and Development Unit (B.A.T. and D.U.) was formed at Boscombe Down, where operational pilots not only received instruction in blind-approach technique but also gained valuable experience in the use and behaviour of the ground and aircraft equipment.[6] From October 1939 until the late spring of 1940 experimental work on the system was continued at Boscombe Down and it was notable that flying was never cancelled that winter on account of weather, except during a 'glazing ice' period in late 1939, even though fog was experienced many times.[7]

Early Use of Standard Blind Approach

Soon after war began the German name *Lorenz* gradually fell into disuse and that of Standard Blind Landing was adopted instead. The original German design had been considerably developed, both by scientists from the R.A.E. and radio engineers from Standard Telephones and Cables, but on 27 April 1940, at a meeting held to discuss the progress report of the R.A.E., the limitations of the equipment were finally officially recognised and it was decided that the description of the *Lorenz* system should be altered from blind-landing to blind-approach equipment; the name Standard Blind Approach was gradually

[1] A.M. File 625411/37. Meanwhile, two types of blind landing equipment, Air Track and Bendix, were purchased from the U.S.A.

[2] A.M. File S.39509.

[3] Installation was complete at Mildenhall, Abingdon, Boscombe Down, Waddington, Wyton, Leuchars, Linton-on-Ouse, Manston, and Upavon and incomplete at Northolt, Hornchurch, Tangmere and Calshot.

[4] Bomber Command File BC/S.20758 Pt. II.

[5] A.M. File S.39509.

[6] A.M. File S.49916.

[7] A.M. File S.67167, and personal account of Air Vice-Marshal Blucke (retd).

adopted throughout the Royal Air Force and abbreviated into S.B.A.[1] It was not until August 1941 that the name of Standard Blind Approach was formally changed to Standard Beam Approach.

Early in the war the Air Staff raised the question of whether S.B.A. was taking up too much of the limited technical and production resources available and all works services on S.B.A. installation were suspended temporarily until the matter had been investigated. The Air Ministry decided that the capacity of radio engineering firms was sufficient to meet all anticipated demands and as far as S.B.A. was concerned all development had practically been completed and the factory was ready for quantity production. Although it was doubted if sufficient time could be made available to train pilots to the high standard required if efficient use was to be made of the system it was decided that the S.B.A. programme should be continued as originally planned.

Headquarters Bomber Command reported in September 1940 that 36 Wellington, 13 Whitley and 9 Hampden aircraft were equipped with serviceable S.B.A. Approximately 30 more aircraft had been fitted but had since been lost. During the first year of the war little progress had therefore been made towards the fulfilment of the aim of large-scale use of S.B.A. by all operational aircraft. An effort had been made to foster a blind-approach training programme and a number of instructors had been trained in the operational use of the equipment at the B.A.T. and D.U., but when they returned to their squadrons they found themselves unable to put their knowledge into use because so few ground installations had been completed and so small a proportion of aircraft were fitted with receivers.[2] The rather disappointing history of S.B.A. during the first year of the war culminated in the disbanding of the Blind Approach Training and Development Unit in June 1940 because events in France made it necessary for all available pilots to be diverted to operational flying.[3]

Operational Requirements for S.B.A., 1940

In the autumn of 1940 Air Ministry interest in S.B.A. was revived as a result of the abnormally large number of flying accidents which occurred at that time. Expert opinion attributed the accidents to the lack of a landing approach system, and an attempt to introduce full-scale S.B.A. installation and training programmes throughout the Royal Air Force was launched. Its value to bomber aircraft was particularly emphasised. The first measures to be taken were those to improve the rate of equipping the Service. Most new aircraft leaving the production lines were already fitted but of the aircraft already in use most were not fitted with the S.B.A. receiver, and in October 1940 the Air Ministry asked the Ministry of Aircraft Production to begin a retrospective installation programme.[4] Aircraft were being delivered at operational units without the equipment and, as there were still some pilots trained in the use of S.B.A., it was essential there should be equipment on which they could practise. Standard Telephones and Cables had produced 1,000 aircraft sets; only 100 Service aircraft, however, were equipped. The remainder of the equipments were being kept at storage and maintenance units until items

[1] A.M. File S.49915.

[2] It was proposed that similar training should begin at Watchfield in January 1940 but delays in building and provision of equipment prevented the opening of the school.

[3] A.M. File S.67167. The unit was reformed shortly afterwards as an R.C.M. Squadron.

[4] A.M. File S.67167.

such as power units became available for installation in aircraft. The rate of production was 300 per month, and whilst aircraft contractors were supplied with sufficient sets to enable them to equip aircraft on the production lines retrospective fitting was to be carried out at Service units by a fitting party to be formed in No. 26 Group and at storage units by No. 41 Group.[1]

The Chief of the Air Staff considered the use of blind-approach equipment so important a factor in aircraft safety, particularly that of aircraft returning from bombing operations, that he called for monthly progress reports from commands on the equipment, training and operational aspects.[2] The reports, first rendered at the end of October 1940, were continued throughout that winter and the following year. Details given were the number of pilots trained, the number of ground and aircraft installations completed, the number of training flights flown and the number of blind approaches made under operational conditions. Information about ZZ approaches was also given.[3]

The drive for the comprehensive installation of S.B.A. and its operational use could only be made effective by an extensive training programme because the system could be used successfully only if pilots were well trained initially and had constant practice subsequently. Between October 1939 and June 1940, when the B.A.T. & D.U. was operating, 187 pilots were trained in the use of S.B.A., but by October 1940 many of these had become casualties and only about 50 pilots were available to act as instructors in bomber units.[4] The first step taken to meet an urgent requirement was the formation, in October 1940, of No. 1 Blind Approach School at Watchfield, where instructors' courses were held with a weekly output of six pilots, later rising to eight, who, on completion of training, were posted back to their squadrons for instructional duties. Output from the one school was insufficient to ensure that the supply of trained pilots kept pace with the installation programmes and it was therefore recommended in November 1940 that blind-approach training flights should be established at the 15 stations where S.B.A. was in operation. However, owing to the shortage of aircraft, flights could be established at ten operational stations only, eight in Bomber Command and two in Coastal Command.[5] Instructors for the flights were given refresher courses at Watchfield. The aircraft allocated to the flights were Whitley Marks I and II, Wellington Mark I and Blenheim Mark IV, all obsolescent types for which overhaul before use was necessary. The S.B.A. aircraft equipment was sent direct to No. 30 Maintenance Unit, Sealand, for installation.[6]

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[1] The No. 26 Group fitting party was eventually located at No. 1 Signals Depot, West Drayton. (Bomber Command File BC/S.20765 Pt. III.)

[2] A.M. File S.67167.

[3] ZZ approaches were made with the assistance of a D/F station suitably positioned near the airfield and in line with a runway clear of all obstruction, and of control officers experienced and suitably trained to undertake the responsibility of landing aircraft under ZZ conditions. It was not considered such a good method as S.B.A. because the responsibility for the approach was divided between the pilot in the aircraft and the controller on the ground. The progress report for January 1942 omitted any record of ZZ approach progress as the method was dying out.

[4] A.M. File S.44162A.

[5] Abingdon, Linton-upon-Ouse, Mildenhall, Wyton, Honington, Waddington, Finningley, and Wattisham. Thornaby and Leuchars. (A.M. File S.44162A).

[6] A.M. File S.67167.

By the end of January 1941, 20 instructors had been trained and were posted to organise the formation of the ten flights. Aircraft fitting was delayed because of late delivery of the aircraft, small supplies of equipment, and snow on the airfield at Sealand. Full-scale training was not therefore possible until March 1941. By the end of that month the eight Bomber Command flights were equipped with two aircraft each, either Wellington or Blenheim, and the two Coastal Command flights with Whitley aircraft. Limited training only was begun at the Coastal Command flights in the early part of 1941.[1] After the establishment of the ten B.A.T. flights all vacancies on courses at the B.A. School at Watchfield were reserved for fighter pilots. Training was given at the Receiver School, Boscombe Down to wireless personnel for the servicing of equipment, and one wireless electrical mechanic was established for each ground installation.[2]

The drive for ensuring that the Royal Air Force was adequately equipped with S.B.A. received renewed impetus once the decision had the full backing of the Air Council. Suitable airfields throughout Bomber, Coastal and Fighter Commands were equipped with the ground equipment from the autumn of 1940 onwards. In November 1940, 17 ground installations had been completed and 14 more were in progress.[3] At that stage the supply of aircraft equipment was not sufficient to enable installations to be made in all aircraft coming off the production lines because of the rapid increase made in aircraft production consequent on the expansion programme. There were many other difficulties to face before S.B.A. could be put into general operational use. The choice of airfields was important in that long runways were as essential as was freedom from obstructions, such as buildings and trees, on the approach path. Another limiting factor in the choice of airfields was that beams operating on the same frequency could not be placed too near each other because of the danger of mutual interference.[4] In March 1941 Headquarters Bomber Command was requested to compile a priority list of S.B.A. requirements at airfields in the command where installation was feasible. In the following month a technical survey of all airfields was arranged, priority being given to Bomber and Coastal Commands and special Regional Control airfields. Satellites and relief landing grounds were included but installations were to be limited to parent airfields if possible. The amount of works services involved in laying the power supply and cables to each of the three beacon positions was considerable but once this had been completed the actual erection of the beacon structure and the installation and setting up of the apparatus took only five weeks. In April 1941 the supplies of beacon cabling were plentiful but labour was not, and considerable difficulty was being experienced in conveying power to the outer marker beacon. A temporary expedient to overcome this was the use of self-powered transportable beacons. In that month it was confirmed that S.B.A. was to be installed at every operational station, Service flying training school, and operational training unit at home and abroad. It was emphasised that when the S.B.A. programme was fully implemented other problems would have to be faced, such as the shortage of servicing personnel and of petrol-electric sets and trailers, and it was decided that solutions to these problems were to be sought immediately.[5]

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[1] A.M. File S.67167.
[2] Bomber Command File BC/S.20785 Part III.
[3] A.M. File S.67167.
[4] A.H.B./II/69/154. Blind Approach Reports.
[5] A.H.B./II/69/189. Blind Approach and Airfield Lighting.

operation of the system at night for operational use and during the day for training or practice flights. One hour for the daily and four hours for the weekly inspection were allotted.[1] The Air Ministry repeatedly stressed the importance of keeping the equipment fully serviceable at all times so that pilots would gain confidence in it.

Beam Approach Training, 1941

Until the middle of 1941 the intensive training effort was confined to the retrospective training of operational pilots. The policy of using small training flights at operational stations was a temporary expedient necessitated by the shortage of equipment; all available equipment was sent to operational units and there was little left over for training units. It was, however, considered that every pilot should be trained in the use of S.B.A. at the very outset of his flying career.[2] In July 1941 the Air Council decided that B.A. training should be incorporated in courses at all Service flying training schools at home and abroad, and instructor training was to be given at the Central Flying School, Upavon. Installation of S.B.A. at flying schools in the United Kingdom was to be on the basis of two ground installations for each school, one at the airfield and one in its vicinity for use when the airfield was congested. Approximately 30 ground transmitters were allocated for use at the Empire Air Training Scheme flying schools abroad.[3]

The retrospective training of pilots was unsatisfactory because it did not keep pace with the intake of pilots; the commands did not make full use of the B.A.T. flights. On 26 August 1941 a meeting was held at the Air Ministry to discuss the B.A. training of bomber pilots. The main difficulty, in the opinion of Headquarters Bomber Command, was the struggle between operational effort and B.A. training, for often pilots were sent on B.A. courses when they were urgently needed for bombing operations. Another argument put forward against too great a concentration of B.A. training was that the use of S.B.A. was often not necessary in practice. Bombing operations could seldom be undertaken if the weather was so bad that it necessitated the use of beam approach on return to the United Kingdom. The existing system meant that a number of operational pilots were trained or partially trained in the use of S.B.A. at about the time when they completed their normal tour of duty. For this reason Headquarters Bomber Command supported the decision to incorporate S.B.A. training at the S.F.T.S. stage so that pilots were qualified by the time they were posted to operational squadrons.[4] In addition to the decision to incorporate S.B.A. training at S.F.T. schools, a further widening of the training programme was envisaged by a recommendation to form 15 new B.A.T. flights. This new total of 23 B.A.T. flights would be able to train 912 pilots per month.[5] Priority was to be given to bomber pilots before they went to an O.T.U. Surplus vacancies were to be given to the retrospective training of operational pilots who had still to complete the greater part of their tour of duty. This would mean that pilots would be trained in the technique early and would go to O.T.Us. with a higher standard in instrument flying and with confidence in the equipment. The proposals were agreed at the end of August, and in September 1941 Air Ministry instructions were issued as to

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[1] Bomber Command File BC/S.20755 Part IV.
[2] A.M. File S.39509, Part II.
[3] A.M. File S.39509.
[4] A.M. File S.67167.
[5] The number of pupils requiring training was 200 per week, rising to 240. (A.M. File S.67167.)

where B.A.T. flights were to be formed and the order of formation. A request from Headquarters Bomber Command that O.T.Us. should be omitted was acceded to as far as possible. Each flight of eight Oxford aircraft was an independent unit, similar to the existing B.A.T. flights, and servicing personnel and instructors were established on a double-shift basis. The flights were lodged on operational stations but all training matters were dealt with by Headquarters Nos. 21 and 23 Groups of Flying Training Command.[1] The flights were disbanded and absorbed into S.F.T. schools when beam approach equipment became available, so that the aim of completing S.B.A. training at an early stage was fulfilled.[2]

Beam Identification

As the number of S.B.A. installations increased, confusion was caused by the number of beams transmitting on the same frequency and being aligned on the same, or approximately the same, bearing. It was difficult to differentiate between them and in some cases pilots returning from operations used the wrong approach beam.[3] In October 1941 Headquarters Bomber Command recommended that an identification letter superimposed on the beam signal should be introduced as a matter of urgency, even if it entailed a short period of unserviceability. This method was followed in the case of the S.B.A. installation used as a radio track guide on the east coast, where it had proved very successful.[4] In December the Air Ministry agreed, as a trial measure, to install equipment to enable the main beacon on six ground installations to transmit an identification letter, although it was not considered to be a satisfactory method in that an interruption of the beam might endanger the safe approach of an aircraft as it neared the inner marker. Another method whereby the beam was unaffected but the dot and dash sectors were broken by the transmission of identification signals was advocated.[5] On 9 March 1942 it was agreed that identification signals should interrupt the beam and should be employed on full-power beams only. Further experiment was necessary before a firm decision was reached on the questions of the speed of keying and the interval between identifications. It was therefore decided that Headquarters No. 80 Wing should monitor German beams which were keyed with recognition signals. A report from No. 80 Wing later in the month stated that the Germans employed the system of interruption of the beam, not superimposition upon it; there was an interval of approximately half a second before and after the identification signal.[6] By September 1944 80 per cent of all airfield beams and all radio track guides in the United Kingdom had been equipped.[7]

Security Measures

When war began certain restrictions had to be placed on the use of S.B.A. to prevent enemy bombers being guided to R.A.F. airfields along the beams. As S.B.A. was of German origin it would be a simple matter for their aircraft

[1] A.M. File S.67167.

[2] A.H.B./II/69/154.

[3] On the night of 26/27 November 1941 the pilots of eleven different aircraft from four stations in No. 3 Group returning from operations went down the Driffield beam thinking they were homing to Marham. This resulted in seven of the aircraft being dispersed on airfields in No. 4 Group. In the same way aircraft of No. 4 Group homed to Marham instead of Driffield. (BC/S.20755, Part IV.)

[4] Bomber Command File BC/S.20755, Part IV.

[5] Bomber Command File BC/S.20755, Part IV.

[6] A.M. File CS.12820.

[7] A.M. File CS.19063.

to be fitted with receivers which could make use of the British beacons as navigational aids. In November 1939 power of the main beacons was reduced so that effective range to an aircraft at 2,000 feet was limited to 20 miles. The system was completely shut down when a 'Yellow' air raid warning was received. In February 1941 instructions were issued that transmitters were to be put into operation only when requested by aircraft captains in bad weather or when they were required for practice or test purposes. If for the latter they were to be closed when a 'Red' air raid warning was received. Headquarters Bomber Command deprecated the security measures as it was felt that they hampered training in beam approach, the most important factor in the successful use of the system. It was pointed out that in bad weather W/T frequently could not be used and thus the aircraft captain had no means of calling for the assistance of S.B.A. In any event, the equipment was designed to be used in conditions of low visibility, when enemy aircraft were unlikely to be operating. It was preferable by far to assist British aircraft and crews in distress than merely to hinder enemy aircraft. The following month the Air Ministry cancelled the instructions and ruled that the equipment was to be operated at the discretion of station commanders; if they considered that visibility conditions were such that R.A.F. aircraft would require approach assistance transmissions from the beacon were to be started. Full power was to be employed at all times so that the utmost help was given to aircraft.[1]

In March 1942 the danger of the enemy making use of S.B.A. transmissions was again considered. By that time there were 38 S.B.A. installations and three radio track guides in almost continuous operation in the United Kingdom, and it was most important to adjudge their value to the R.A.F. compared with their value to the enemy. One solution to the problem was presented in the fact that as the number of installations increased they would have to be operated on low power to avoid mutual interference because of the limited number of frequencies available. The range of low-power installations was about 25 miles only and security would be further increased by the proposal to use the same frequency for parent and satellite airfields and then to ring the changes on the installations. Radio track guides would of necessity have to be used on full power and when it became obvious that the enemy were using them they were to be subject to radio control by Headquarters Fighter Command. Under these arrangements, if information obtained by Headquarters No. 80 Wing made it clear that enemy aircraft were using an S.B.A. installation the Radio Control officer at Headquarters Fighter Command was to be informed and he was to order that station to cease S.B.A. transmissions. In the same way Headquarters Fighter Command was to be informed when it was certain that the enemy was no longer using the beam. No S.B.A. installation was to be closed down unless the denial of its navigational aid to the enemy outweighed its value as a homing or approach aid to Allied aircraft. These instructions were issued but were to be held in abeyance until it was believed that enemy aircraft could tune in to British S.B.A. frequencies. Security control of the identification signals was also required. The safety measures were planned to meet this danger; identification signals were so constructed that they were capable of being turned off at any given moment. If it were ascertained that enemy aircraft were using S.B.A., identification letters would be changed daily.[2]

[1] A.M. File S.39509.

[2] Bomber Command File BC/S.20755.

Operational Use of S.B.A., 1941/1942

In the autumn of 1941 attention was once again focused on the extent to which S.B.A. was being used operationally. On the night of 20/21 September 1941 unusually heavy losses were incurred by bomber aircraft on returning to bases from operations. The Air Ministry asked Headquarters Bomber Command whether the universal use of S.B.A. would have reduced the losses to any appreciable extent. It was emphasised that for one year much money and effort had been expended on providing S.B.A. ground and aircraft equipment and in training pilots to use it. The need for training was stressed because constant practice and familiarity with the equipment gave the pilot confidence in using it. The formation of the B.A.T. School at Watchfield and the B.A.T. flights on operational stations had been the result of this policy. It was clear from the replies given by Headquarters Bomber Command that the measures taken to ensure the safety of aircraft on return from bombing operations relied far less on general use of S.B.A. than on a policy of diversion throughout the command. If an airfield was shrouded in fog pilots were ordered to land on clear airfields rather than risk aircraft and crew by attempting a fog landing with the aid of S.B.A. The landing of an aircraft on a strange airfield, even though free from fog, often led to accidents. In September and October 1941 bombing operations were considerably hampered by bad weather and little effort was made to alleviate its effect by the use of S.B.A., which by that date was readily available. On many nights it had been found impossible to operate at all even though the weather over enemy country was good, because the weather over the home bases was expected to deteriorate by the time the bombing force returned.[1]

By October 1941 S.B.A. was available at 35 stations and the supply of aircraft equipment was satisfactory.[2] Training at the original 10 B.A.T. flights was at the rate of 200 per month but the formation of the 15 new flights was very slow. Many difficulties were being encountered, chief among them being the delay in completing ground installations. This was caused by large-scale extensions and alterations to airfields, and the slow provision of control and power cabling to the beacon sites by the Air Ministry Works Department because of the labour shortage.[3] However, training at some had begun by October 1941. At the same time the Air Ministry continued to urge the importance of post-graduate practice by pilots who had already completed an S.B.A. course and had returned to operational flying. Headquarters Bomber Command agreed that continued practice was important but considered that congestion was caused by the allocation of non-operational B.A.T. flights to operational and O.T.U. stations. In bad weather the number of aircraft using a beam was strictly limited and as the B.A.T. flights had to be given priority, opportunities of giving pilots post-graduate training were very small. Therefore the removal of non-operational B.A.T. flights from Bomber Command airfields was requested. The Air Ministry found that this was not possible because of the leeway in training which had to be made up, and considered that congestion would be relieved by the proposed extension in January 1942 of each S.B.A. course from seven to fourteen days. Both types of training could be carried out if the training were properly organised, and each station was to ensure that the best possible use of the beam was made while operational flying was in progress.[4]

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[1] A.M. File S.67167.
[2] A.M. File S.74991.
[3] A.M. File S.39509, Part II.
[4] A.M. File S.74991.

As the number of beams in use increased, the problem of the frequencies on which new beams were to operate became more urgent. S.B.A. aircraft equipment could be set to select six spot frequencies from about 40 frequencies available in the band. All ground installations were working at full power and had a range of about 100 miles, so it was necessary for two stations working on the same frequency to be separated by at least 200 miles. To fulfil the intention of installing S.B.A. at 250 airfields it would be necessary to restrict ranges. The alternative was to reduce the number of installations. On 9 March 1942 a meeting was held at the Air Ministry to discuss the question and it was agreed that beams would have to operate on low power as the number of installations increased. This was not an ideal solution as low-power beams could be used only in the approach role and were of no use as navigational aids, at that time a more important function, but it was unavoidable until more frequencies could be made available. It was intended that S.B.A. should be used more extensively in the future as a landing approach system in bad weather, and with the increased use of Gee the need to use S.B.A. beams as homing aids would lessen. It was agreed that the operation of radio track guides on full power was to be continued as they were designed solely as navigational aids. The question was again considered by Headquarters Bomber Command in May 1942. It was decided that the range of most beams should be limited to 25 miles so that two beams on the same frequency could be located as near as 50 miles to each other.[1]

Operational Use of S.B.A., 1942/1943

By the beginning of May 1942, 40 S.B.A. ground installations were in operation; 25 at operational airfields, nine at O.T.Us., three at training airfields and three as radio track guides.[2] By the end of June, 49 S.B.A. installations were in service, 15 were in course of installation, and the necessary cabling was being laid at another 100 airfields.[3] The installation programme continued to make progress at home and abroad, where some mobile installations had been shipped for use at flying training schools; 35 of the first 66 transportable sets ordered were allocated to the Empire Air Training Scheme.[4] The greater proportion of S.B.A. ground equipment which became available in 1942 was allocated to training units at home and abroad with the intention that great emphasis should be laid on the system in the early stages of pilot training. It was hoped that pilots would be full of enthusiasm for the system by the time they joined operational units. Equipment was allocated strictly according to the degree of priority accorded to each airfield and so that beams operating on the same frequency were sited far enough apart to avoid mutual interference. The priority list was changed only when exceptional requirements arose. The production of aircraft receivers also proceeded steadily, and by the end of November all bomber and appropriate training aircraft were being delivered from the production line equipped with S.B.A. and there was an ample reserve of replacement equipment. 75 ground installations were available for use and a further 126 were in process of installation or reinstallation. 50 transportable sets had been sent overseas for use in training units.[5]

Repeatedly throughout 1942 the Air Ministry emphasised the value of S.B.A. and the importance of all pilots using it for landing approaches in bad weather. Increased use of the system would result only when all concerned were convinced

[1] A.M. File CS.12820. [2] A.H.B./II/69/154. [3] A.M. File S.74991.
[4] A.M. File S.39509, Part II. [5] A.H.B./II/69/164.

of its value to aircraft safety. It was considered necessary for every pilot to have adequate basic training in the use of the system and constant practice thereafter so that its use in emergency became automatic and he was fully confident of his ability to land in perfect safety in poor visibility.[1] This confidence had to be further strengthened by ensuring that the equipment was always in perfect working order and all technical faults had been eradicated. After this confidence had been ensured it was the responsibility of Headquarters Bomber Command to order diversions only for pilots whose flying was not of a sufficiently high standard to permit them to land on the beam when bad weather prevailed at the home airfield.[2]

Ground installations were completed at nine Coastal Command and two Fighter Command airfields but these were primarily for the assistance of bomber aircraft diverted from their home bases. In Coastal Command the use of S.B.A. was being superseded by that of A.S.V.B.A. and in Fighter Command V.H.F.B.A. was used.[3] On 2 April 1942 Headquarters Coastal Command informed the Air Ministry that there was no requirement for S.B.A. in Coastal Command aircraft other than long-range fighters. It was therefore arranged that no installations were made but the provision of fixed fittings and wiring was continued so that S.B.A. could be installed if the aircraft were diverted to other commands. A.S.V. was being installed in all Coastal Command aircraft except long-range fighters and its use in conjunction with B.A.B.S. provided an adequate approach system.

S.B.A. was used mainly by Bomber Command. During the first half of 1942 the number of adequately trained operational pilots and the number of bomber aircraft fitted with serviceable equipment were approximately doubled and the number of available ground stations was increased by 50 per cent. The training programme was satisfactory because by June 1942 the effect of the formation of the 15 new B.A.T. flights had been felt. The number of pilots trained increased each month and in June alone it was 1,145. It was estimated in the summer of 1942 that by the following winter most of the operational pilots in Bomber Command would be fully trained. In an effort to ensure that post-graduate training was not neglected Headquarters Bomber Command issued instructions that each pilot was to make two practice approaches a week; experts believed this to be the minimum for pilots to remain competent in beam approach technique. These practice approaches were not scheduled as special training flights but were carried out on normal training or operational flights, even when blind flying conditions did not exist.

In spite of this there had been little increase in the operational use of S.B.A. and by this very fact it appeared that all the expenditure of money, manpower and productive effort had been wasted. The main reason was that, instead of making use of S.B.A., aircraft were diverted to airfields where the weather was suitable for visual approach and landing. Many bomber pilots lacked confidence in S.B.A. because there was no reliable means of ascertaining the height and position of the aircraft in the final stage of the approach to the runway and they were afraid of flying into the ground. The S.B.A. approach procedure in itself was complicated and was another reason why pilots were disinclined to

[1] 100 yards horizontal and 100 feet vertical. [2] A.H.B./II/69/154.

[3] 185 aircraft only in Coastal Command were fitted with S.B.A. receivers. (A.H.B./II/69/154.)

make use of the system.[1] Constant practice was essential but at most units operational pilots found they were unable to make training flights because, during the periods of intensive operations, the intervals between operations were used for S.B.A. servicing; also, so much work was involved in moving heavy bomber aircraft from a dispersal point for flying that pilots were reluctant to fly except on operations. The S.B.A. method of approach required a high standard of instrument flying from the pilot and this additional strain, imposed after an exhausting bombing raid, was often too much for him, particularly if he was flying a damaged aircraft. Bomber pilots, did, however use S.B.A. beams a good deal for homing.[2]

The problems that hindered the full use of S.B.A. in bombing operations were so numerous that, in October 1942, the Beam Approach Development Unit was formed at Watchfield. The object was to develop all types of beam approach technique and to incorporate improvements in the equipment. The unit was adminstered by the Flying Training Command unit at Watchfield but was operationally controlled by the Air Ministry.[3] Naval aircraft and personnel were included and in all experiments and research the closest co-operation was maintained with the Admiralty. One of the main problems to be solved was that of speeding up the rate of landing, which at that time was four heavy bombers per hour, too slow for Bomber Command operational requirements. A new system had already been tried out at Watchfield in July 1942. In this aircraft were brought in, without using the existing complicated procedure, from a 'stand-off' marker beacon which was placed eight miles in front of the main transmitter. It was considered that if this method was satisfactory 15 medium or 10 heavy bomber aircraft could be landed in an hour. After the formation of the B.A.D.U., trials of the procedure continued simultaneously with trials of a method in which two adjacent beams were used, one as a stand-off beam while aircraft were brought in on the other. Other schemes which were tried out included the effect of narrowing the beam to a width of 1½ degrees. Tests of the Standard Telephones and Cables glide path indicator, which had been started at Polebrook in the previous August but had been abandoned because they caused interference with operational flying, were continued so that the necessary landing technique could be evolved, and trials of a multi-channel S.B.A. receiver were begun.[4] In November 1942 the experiments to discover a feasible means of landing heavy bombers quickly were transferred to Downham Market, where, with the aid of No. 218 Squadron (Stirlings), trials were undertaken of radio altimeters, the glide path indicator, and automatic control of the aircraft in azimuth.[5]

During the winter of 1942/1943 the question of abandoning the use of S.B.A. was broached. Headquarters Bomber Command stated that the system was seldom used for the purpose for which it was provided. Landings were certainly made with its help after operations but only in a few instances was the weather so bad that landing would have been impossible without S.B.A. The Bomber Command view was that there was no real need for S.B.A. because

[1] An aircraft approaching on the beam had to carry out an elaborate figure-of-eight course before landing. The procedure involved the pilot getting himself to the correct height at the inner marker beacon for making a normal landing, to achieve which might require several attempts. (A.H.B./IIE/76A—War in the Ether.)

[2] A.M. File S.74991.

[3] Directorate General of Aircraft Safety.

[4] A.M. File S.74991.

[5] A.M. File S.87187.

the operational policy was to launch full-scale bombing raids only on nights when the weather was favourable. It was recommended that only one airfield in three should be equipped with S.B.A. This was considered to be necessary in any event because of the limited number of frequencies available and the geographical spacing required to avoid mutual interference. It was considered that the economies would in no way detract from the operational efficiency of the command.[1] However, the S.B.A. programme had involved considerable expenditure in money, labour and material, and it was not until the winter of 1942/1943 that the full effect of the intensified S.B.A. training, introduced about one year earlier, began to make itself evident. The Air Ministry hoped that increasing use of S.B.A. as a landing approach system would be made as crews became more experienced and more confident. Some aircraft from Holme on return from operations had used S.B.A. for landing in visibility of 300 yards, one of them with a full load of bombs and only three serviceable engines. This was held to be an encouraging sign of increased enthusiasm for S.B.A. among bomber pilots and it was urged that a decision on the future of the system should be deferred until the summer of 1943 when its value during winter operations could be more fully assessed. In deciding the future of S.B.A. various factors had to be considered, chief among them being the good supply position and the absence of a suitable alternative. It was believed by the Air Staff that the policy of diverting aircraft would not meet the problem raised if and when unexpected bad weather caused bomber bases to become unfit for normal landings whilst aircraft were on bombing raids. There would almost certainly be congestion over the clear airfields, and then the emergency runways and S.B.A. equipment would be called into use. Another factor to be considered was the growing activity of enemy night-fighters over Germany, which was so endangering the safety of Allied bomber aircraft that the only possible solution appeared to be that of sending bombers over in weather too bad for fighter operation.[2] Also, between July and December 1942, 197 bomber aircraft crashed when attempting to land or descend through bad weather on return from operations. Some of those accidents might have been avoided if pilots had been skilled in the use of S.B.A. and if it had been regarded as the normal method of approach through cloud or in bad visibility.[3] The Air Ministry considered that nothing would be gained by drastic curtailment of the S.B.A. programme but recommended that economies should be effected by limiting ground installations to 50 in Bomber Command, provided that a constant review of requirements was maintained. The installation of S.B.A. receivers in all bomber aircraft was to be continued and intensive training was to be aimed at with the object of achieving satisfactory landings in visibility as low as 100 yards. Research and trials were to go on in an attempt to improve the system; it was believed at both the Air Ministry and Headquarters Bomber Command that the value of S.B.A. would be enhanced with the incorporation of improvements then undergoing trial.[4]

Investigation by the Inspector-General of the R.A.F.

The feeling that some modification of the S.B.A. programme was necessary was so widespread that, at the third meeting of the Committee for Co-ordination of the Bomber Offensive, the Secretary of State for Air directed that a committee

[1] A.M. File S.87187. [2] A.H.B./II/69/154. [3] A.M. File CS.18395.
[4] A.H.B./II/69/154.

be convened to review the existing S.B.A. policy in the hope of effecting economies. The committee met at the Air Ministry on 18 December 1942 and consisted of representatives of the Air Ministry, Headquarters Bomber Command, Headquarters Flying Training Command and the U.S.A.A.F. It was agreed that the S.B.A. programme should be reduced in Bomber Command to one installation per clutch of three operational airfields except that all O.T.U. airfields, and those at which pathfinder squadrons were based, were to have one installation each. S.B.A. was also to be installed at all Flying Training Command airfields, and a total of 33 equipments was required to meet planned commitments up to the end of 1945. Bomber Command requirements were to be reviewed once more when the trials of various systems had been completed. When the decisions were made known to the Chief of the Air Staff he was assured that the effort expended on S.B.A. was justified by the immense assistance the system would render to the bombing offensive, but he was doubtful of the efficacy of S.B.A. He did not consider valid the argument that use of S.B.A. would increase the number of bombing raids by making it possible for them to be carried out in worse weather than was otherwise practicable. He believed that the average pilot would not achieve a high standard in S.B.A. technique because an average operational tour was not long enough to permit it. However, he did not want to obstruct the development of any system that could in any way benefit the bombing offensive and suggested that the Inspector-General of the R.A.F. should be asked to report on the operational use of S.B.A. and to advise whether he considered that it would increase the effectiveness and lower the casualty rate of Bomber Command. The Secretary of State of Air agreed on 23 December 1942 that investigation should be carried out as a matter of urgency.[1]

As a result the Inspector-General of the R.A.F. undertook a detailed and thorough investigation of the operational use of S.B.A. In his report, which was issued on 21 January 1943, he stated that Bomber Command was fully committed to the use of S.B.A. and a great deal of effort had been put into implementing the original scheme, which was 70 per cent complete. S.B.A. was being used for many purposes including approaching and lining up on the runway in bad visibility, homing, as a navigational aid or check, as a means of keeping on the circuit of an airfield in bad visibility or above cloud, and for providing the starting point of an outward course when over cloud. It was used very rarely for blind landings and then only by experts, and was very little used for breaking cloud. The use of S.B.A. had been increasing before the introduction of Gee, especially for homing, but since then most pilots had not used the beam, particularly as they had little operational practice. Pilots did not like S.B.A. because the approach procedure was complicated and they felt its use was dangerous. The Inspector-General considered that the operational results obtained from the use of S.B.A. did not justify the effort expended on it but thought that its value to the Service could be enhanced. The first essential was to inspire pilots with confidence. He urged that it should be emphasised that S.B.A. was designed to help an aircraft approach within sight of the runway; if it was regarded as a blind-landing system pilots would think that they might be required to land in difficult and dangerous conditions. As things were, they preferred to be diverted rather than to attempt landings by S.B.A. It should be available for pilots who were able to

[1] A.M. File S.87187.

use it, and they should be allowed to use it if they so wished instead of being compulsorily diverted to another airfield.[1] The Inspector-General insisted that, above all, constant practice was essential before S.B.A. could be successful. Such practice was normally very difficult to fit in on operational units so he recommended that S.B.A. should be used as the standard mode of return to base from operational sorties, and that for this a satisfactory and simple control system to speed up the rate of landing was necessary and very important. If a faster rate could be achieved further development of S.B.A. was considered to be justifiable.[2]

The Inspector-General recommended that a straight approach technique, using a distant marker or distant homing beacon on the front beam, should be adopted. Such a method would be much simpler than the figure-of-eight approach and trials should be arranged right away. If straight approach on the front beam was possible then elimination of the back beam to reduce congestion should be considered. If the back beam could be eliminated attempts should be made to make S.B.A. mobile instead of being anchored to one runway. He understood permanent aerials could be erected for each runway and the transmitters made mobile. The provision of short straight lines of four contact lights between the outer and the inner marker were recommended so that the pilot could line up on them. A further suggestion was the provision of more by-tracks from the main runway so that aircraft could be got away quickly. The Inspector-General recommended that a variable tuning device, used by the Fleet Air Arm, should be incorporated in the S.B.A. receiver because that would eliminate the existing tuning troubles and increase the number of frequencies available for use. He considered that the introduction of the new radio glide path indicators would be helpful in giving confidence to the pilot, an essential prerequisite, when he was descending through cloud. The use of an electrical low-reading altimeter might similarly instil confidence when S.B.A. was used in very bad weather.[3]

The recommendations were studied by the Air Ministry, and those considered feasible were incorporated in S.B.A. development. It was possible to erect permanent aerials so that mobile equipment could be used but it was not considered worth while in view of the extra expenditure and time involved, because it would take about one day to realign a beacon to its aerial array every time it was moved. There were disadvantages as well as advantages in the incorporation of a variable tuning device in the aircraft receiver. Among the advantages was the fact that the pilot would be able to choose any channel on the band instead of being restricted to six frequencies, and the amount of servicing required would be considerably reduced. No test oscillator would be required except for tuning the marker receiver and for a periodic check on the main receiver, whilst the trimmer condenser and the wave-change switch, both weak features, would be eliminated. On the other hand the identification problem would be intensified as the pilot would be able to choose any frequency. This meant that each beam would have to transmit identification signals and each aircraft would have to carry a list of the code. In order to send identification signals the beam approach signals would have to be

[1] A.M. File CS.18395.

[2] On 18 January 1943 one of the Lancasters returning from Berlin had to wait one hour and twenty minutes over its base before being allowed to land. (A.M. File CS.18395.)

[3] A.M. File CS.18395.

interrupted and this might have an adverse effect on an approach made by pilots unskilled in S.B.A. flying. If so, identification signals would have to be stopped during approaches and the result would be to slow down the rate of landing. The installation of a remote control tuning head was essential in order to facilitate tuning and this complicated the aircraft installation. It had to be placed so that it could be easily seen by the pilot and had to be illuminated for night use. Another point requiring consideration was the threat to security as all airfields would be made identifiable to the enemy.

At the Air Ministry it was considered that the disadvantages could be overcome. Interruption of the beam was standard procedure on the radio range system in the United States of America. The provision of remote control would be the greatest difficulty. It was preferable that the tuning head should be near the pilot, but if this was not possible it could effectively be located near the navigator or wireless operator. The threat to security was not then very real because, as far as was known, the enemy had not adjusted his aircraft receivers to the Allied frequencies.[1] The Chief of the Air Staff approved the incorporation of a tunable receiver and at the end of March 1943 several sets were suitably modified by Standard Telephones and Cables and were tested by No. 101 Squadron at Holme. During 1943 no large order was placed because of indecision regarding the future of S.B.A. and because full-scale production would hamper the production of other equipment; Headquarters Bomber Command preferred that supplies of S.B.A. should be slowed up rather than that the production of such systems as H2S, Monica, and Gee should be hindered.

There were two designs of tunable receiver, the R.1466, mechanically-tuned equipment, and the S.B.A.–X, later known as the R.1544, electrically-tuned equipment. The first was the best tunable equipment that could be produced as a relatively minor modification of the fixed-tune receiver but the S.B.A.–X was a completely new design and had many advantages over the former. Mechanically-tuned receivers were fitted in Mosquito aircraft of No. 1409 Meteorological Flight at Oakington for Service trials in the summer of 1943. The range of the installation was approximately 7 to 10 miles in normal conditions at a height of 2,000 to 3,000 feet. Sensitivity varied according to the direction of the aircraft in that signal strength was much greater when flying towards the main beacon than in the opposite direction. The tuning indicator was comfortably positioned for the pilot and was easily read in all conditions. Calibration was fairly accurate throughout the range of 30 to 40 megacycles per second but the identification of beams by keyed letters was necessary in order to ensure accuracy in homing. Servicing was very much easier because the components which gave the most trouble in the fixed receiver were eliminated.[2] The trials were so successful that Headquarters No. 8 Group (P.F.F.) requested that all its operational aircraft should be fitted with the tunable S.B.A. receiver in the existing form; improvements were to be incorporated later as modifications. The Air Ministry agreed at the end of September to provide 60 receivers for extended trials. In November Headquarters No. 8 Group stated a requirement for 150, but provision on such a scale was difficult because of the decision taken on 5 November 1943 not to renew the existing S.B.A. contract but to concentrate on the installation of

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[1] A.M. File CS.18395.

[2] Bomber Command File BC/S.20765/2.

G.C.A. and B.A.B.S. Although large-scale production of the tunable receiver was impossible it was agreed that a requirement for a small number of tuning controls could be met by a continuation of an existing small contract for transport aircraft installations. Headquarters Bomber Command required the installation of tunable receivers in aircraft of Nos. 139 and 627 Squadrons and Nos. 1409 and 1507 Flights because they frequently operated when the weather was so bad that operations by the main force were impracticable. 60 receivers were required initially and thereafter 10 per month. In December the Air Ministry allocated 100 to Bomber Command because the Transport Command requirement had been cancelled. In January 1944 Headquarters Bomber Command reported that the use of tunable receivers by Mosquito aircraft of No. 8 Group was giving very satisfactory results and asked for the provision of an additional 150. This was agreed by the Air Ministry but production was not guaranteed before July 1944.[1]

In August 1944 it was estimated that electrically-tuned receivers could not be produced for at least eighteen months, but a supply of mechanically-tuned receivers, sufficient to meet the requirements of Flying Training Command for the next two years, could be adapted immediately from existing stocks of fixed-tune receivers. This was considered to be sufficient because it was believed that in two years' time Flying Training Command would have been equipped with V.H.F. R/T equipment and would be able to use V.H.F. B.A.[2] In October 1944 electrically-tunable receivers were installed in one Lancaster Mark X and two Halifax Mark III aircraft at Ludford Magna and Service trials were held throughout that month and the following one. The pilots who carried out the trials were experienced S.B.A. pilots and they considered the equipment to be superior to the fixed-tune receiver, both in sensitivity and in selectivity. As a result Headquarters No. 6 Group stated a requirement for its installation as the prospect of obtaining B.A.B.S. seemed very remote. The requirement could not be met because of the production delay and Headquarters Bomber Command preferred to make immediate use of mechanically-tuned receivers and to rely on G.C.A. and B.A.B.S. as long-term approach systems.[3]

On 16 November 1944 the Air Ministry decided that further development of electrically-tuned receivers was to stop, and that mechanically-tuned receivers were to be installed, on the production lines, in all aircraft which were to be fitted with S.B.A. Production of the new receiver would be achieved by modification of the fixed receiver R.1124, of which there was a stock of 16,500. Delivery of the tunable receivers was not as speedy as had been anticipated, however, and in June 1945 the Air Ministry was forced to issue instructions that certain aircraft were to be equipped with the fixed-tune receivers. These were to be replaced when tunable receivers became available. It was estimated that main production would begin in January 1946 when priority of installation would be allotted to training aircraft because S.B.A. would be the only approach system available to them.[4]

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[1] Bomber Command File BC/S.20755/2.

[2] A.M. File A.85487.

[3] Bomber Command File BC/S.20755/2.

[4] A.M. File S.87187, Part II. Mosquito aircraft of Bomber Command which were equipped during the summer of 1945 retained the equipment.

Experiments were conducted in No. 26 Group on the possibilities of distinguishing between the front and back beam. There were two possible methods. The simplest was one in which a screen provided with an earthing switch was placed behind the beam aerial. When the screen was earthed signals were received normally. When the screen was isolated the pilot could home towards the main beacon by turning the aircraft through 360 degrees and flying the heading on which maximum signal strength was received. The second method was less clumsy; the two letters of the identification characteristic were so transmitted that when the pilot received the signals in the front beam the first letter was picked up at a greater strength than the second; in the back beam the reverse was the case. If a pilot approached the main beacon at right-angles to it the two letters were heard with equal intensity. It was considered that the second system was the more successful but its introduction entailed the use of an entirely new equipment designed by Marconi; the existing ground equipment manufactured by Standard Telephones and Cables could not be modified. It was the method eventually chosen but by the time all technical difficulties had been overcome the decision to abandon operational use of S.B.A. had been taken. Installation was therefore restricted to radio track guides and the installations retained for use by training aircraft.[1]

In March 1943 the R.A.E. was instructed to investigate the problem of back-radiation. The object was to reduce its strength but at the same time to keep the beam-width within reasonable limits. The early research was done on the V.H.F. approach beacon because of its smaller size and it was believed that if a satisfactory solution to the problem was found for aerials operating on 120 megacycles per second, a similar scheme could be easily adapted for aerials operating on 30 to 40 megacycles per second. After experiments with reflectors behind the aerial array had been conducted work was transferred to the S.B.A. transmitters. The solution of the problem was achieved after about three months' work by clamping two reflectors to a tube frame which was attached to the centre S.B.A. mast. A further mast was erected behind to increase stability. The result was an increase in range of the front beam to about 45 miles and a decrease in that of the back beam to about 10 miles.[2]

Certain economies were effected in the S.B.A. equipment programme as a result of the Inspector-General's report, but supplies could not be drastically reduced because there was nothing to replace the system. Before the report was issued the aircraft equipment programme was planned to cover all aircraft for which S.B.A. was approved, plus maintenance requirements and a stock to meet contingencies. The normal stock holding was for six months, covering both aircraft equipment and maintenance. It was decided to reduce the stock to that required for three months' aircraft supply and six months' maintenance. As a result of this economy the number of sets ordered on the existing contract was reduced. It was agreed that installation of ground equipment should proceed at the rate of one beam for each clutch. Cabling of all new stations was continued and installations were to be completed if they were so far advanced that there would be no material saving if work was stopped.[3]

Another result of the Inspector-General's investigation was that the trials in which S.B.A. was being used as a method of controlled approach to the airfield were intensified. The Inspector-General considered it to be a promising

[1] A.M. File S.87187. [2] R.A.E. Technical Note No. 135. [3] A.M. File A.85487.

line of development but thought that Downham Market was unsuitable because the surrounding flat country made approach very easy. He recommended Holme as a more suitable location for the experiments because it was in difficult country and because the station was commanded by an S.B.A. expert and enthusiast.[1] The Air Ministry agreed and the trials were continued by No. 101 Squadron. They lasted from 10 April to 4 May 1943 and were designed to find out whether a method of approach known as the 'Gate' procedure was workable. This entailed the placing of an additional marker, the gate, in the beam at a distance of 5½ miles from the outer marker. When aircraft were 40 miles from the gate their estimated time of arrival at the marker was passed by R/T to flying control at the airfield. If more than one aircraft estimated similar times, flying control regulated them by instructing others to delay their arrival by an appropriate number of minutes. When a pilot reached the gate and heard the marker signal he announced his identity and was instructed by the controller either to go ahead or to wait for a certain period. This filtering was necessary so that aircraft might fly along the beam safely. Once the pilot was authorised to go ahead he flew down the beam and again announced his identity after passing the outer marker, and landed on the appropriate runway after being given appropriate instructions. The procedure involved certain modifications to the aircraft receiver and the addition of the extra marker on the ground, whilst it was necessary to replace the TR. 9 with the TR. 1196 because the former provided insufficient R/T range. The objects of the trials were to find out whether the procedure could be used by an average bomber pilot on return from operations, whether it would speed up the rate of landing, and whether it could be used in low visibility. The results were rather disappointing. It did not appear to be a working proposition when used by the average pilot trained to wartime standards.[2] The trials were successful for seven operational nights when the weather was clear but on the eighth, with a fog bank between the outer and inner markers, three crashes occurred. Later investigation revealed that on the clear night pilots were flying by visual contact though no doubt using the beacon as well. On the eighth night the inexperienced pilots were unable to fly accurately by the beam alone.[3] It placed too great a reliance for accurate timing on navigators and pilots fatigued on return from operations and imposed heavy strain on flying control staff. It was considered that the standard of instrument flying of most wartime-trained pilots was not high enough for a safe final approach in poor weather conditions. The failure did not rest entirely with the pilot as the existing blind-flying instruments were not sufficiently accurate and further research was needed. It was clear that the first essential for increasing the rate of landing was experienced crews and ground staff.[4]

Decision to Substitute B.A.B.S. and G.C.A. for S.B.A.

One of the most important factors which had governed the policy of S.B.A. provision was the absence of an effective substitute; even if S.B.A. was not used extensively for the purpose for which it was intended it was the best approach system then available.[5] However, whilst the wisdom of expending still more effort and resources on its further development was still being

[1] Group Captain R. S. Blucke, the pilot who carried out the first trials in England of the *Lorenz* equipment in 1936. From 8 November 1940 to early 1942 he had been at the Air Ministry (T.F.3) in charge of the arrangements for S.B.A. training.
[2] A.M. File S.94886. [3] A.M. File S.94886. [4] A.M. File S.87187.
[5] A.M. File S.87187.

questioned a new approach system came to the notice of the Air Staff. This was Ground Controlled Approach, invented by an American, Dr. L. W. Alvarez. The system was given trials in the United Kingdom in July and August 1943; these proved that G.C.A. was the safest and most efficient radar approach system then invented. The discovery of this new method had a great effect on the future of S.B.A. By September 1943 a declaration of Air Staff policy on its continued use within the Service was urgently required because since publication of the Inspector-General's report that its operational use in Bomber Command did not justify the effort expended on it anxious queries had been received from overseas flying training schools as to whether S.B.A. was still being used operationally. Reports that little use was made of it had reached them and the authorities considered that, if this was so, the extensive training and the installation of the equipment was unnecessary. The Air Ministry was unable to give a definite decision on the future operational use of S.B.A. but the overseas flying training schools were assured that, although the value of the extensive S.B.A. programme had been questioned, the only alternative approach system was G.C.A., the widespread adoption of which seemed unlikely for at least eighteen months.[1] Therefore, S.B.A. training was to be continued, especially as it provided invaluable instrument training. In September 1943 a committee was formed to investigate the requirements of radio aids for flying control and to recommend what the future Air Staff policy should be. Special attention was paid to the needs of Bomber Command. The report of the committee, published at the end of September, stated that S.B.A. was an efficient navigational aid and could be used as an approach aid but it was very little used by operational aircraft as an aid to landing in bad weather. It referred to the opinion of the Inspector-General that the effort put into S.B.A. was not justified by the operational results but that it could be a valuable method if pilots had confidence in their ability to use it and a control method was evolved to speed up the rate of landing. Some of the technical improvements which the Inspector-General had recommended had been incorporated but the main one, the introduction of a variable tuning receiver, had been delayed until the future of the system had been decided because it entailed a major production programme which could not be completed for two years. The committee considered that the failure to employ S.B.A. on a large scale was attributable to several causes; training difficulties, technical faults, and the strain endured by the pilot because he had to interpret aural signals in addition to carrying out normal instrument flying. By April 1943 40,000 aircraft sets had been manufactured and a further 22,000 were on order. This involved great expenditure of productive effort, manpower and material which hampered the manufacture of radar systems. The final recommendation of the committee was that if there were available an effective alternative equipment which relieved the operational strain on the pilot and could be produced and operated economically, it should be substituted for S.B.A. The existing S.B.A. equipment could be used for training because it was an excellent aid to instrument training. The relative merits of two other approach systems were assessed, Radar Beam Approach Beacons and Ground Controlled Approach. It was stated that both S.B.A. and Radar B.A.B.S. required a radio glide path indicator for perfect presentation because neither of them indicated the position of the aircraft on the correct glide path. The committee considered that G.C.A.

[1] A.H.B./ID/12/308. Standard Beam Approach.

should be adopted as far as possible and that where its use was limited because of the communications problem Radar B.A.B.S. should be employed. Contracts for S.B.A. equipment could be adjusted so that the supply to Bomber Command could continue until the alternative systems were available.[1]

On 5 November 1943 the Air Staff agreed that G.C.A. should replace S.B.A. where it could be made available and that the radar beam approach equipment should be fitted where it was impossible to site G.C.A. installations. The use of S.B.A. was to be gradually discontinued and the existing contract for it was not to be renewed. This contract would provide sufficient S.B.A. equipment to fulfil 100 per cent of aircraft requirements until September 1944 and 50 per cent for the first six months of 1945. If the production and use of G.C.A. and B.A.B.S. were unsatisfactory the contracts could be renewed in the middle of 1944, and 1 July 1944 was chosen as the date for review of the position. Although the operational use of S.B.A. was to be discontinued it was to be retained at advanced flying training schools because S.B.A. training ensured a satisfactory standard of instrument flying.[2] The use of S.B.A. overseas had been confined to the Empire Air Training Scheme flying schools and it was never installed for operational use in the Mediterranean, India or South-East Asia theatres of operations. The decision was straightforward but its implementation was made difficult because the introduction of G.C.A. and B.A.B.S. took longer than had been anticipated. It was obvious that the changeover would take some time and the Air Staff wished the use of S.B.A. to be continued until it was completed. But in the early months of 1944 it appeared that use of S.B.A. was becoming increasingly neglected, not only operationally in Bomber Command but also in training at the advanced flying training schools. On the night of 16/17 December 1943 exceptionally heavy losses were incurred by Bomber Command aircraft on return from operations. The Inspector-General conducted an enquiry and attributed the losses to two causes; one, the lack of any pre-planning and practice of a scheme for homing in bad weather and, secondly, the almost complete neglect of S.B.A. It was noticeable that losses were light in No. 5 Group, where bad-weather homing plans were carefully worked out and the majority of crews were kept in S.B.A. practice. The Inspector-General stated that an impression that S.B.A. was obsolete had been created. Consequently S.B.A. was tending to be devalued within Bomber Command and it was feared that heavy losses in men and aircraft would result. The Air Ministry considered, however, that there had been no appreciable reduction in the use of S.B.A., and it was concluded that neglect of S.B.A. was not the primary cause of the heavy losses in December.[3] Headquarters Bomber Command believed that

[1] A.M. File S.87187.

[2] A.M. File S.87187.

[3] Number of occasions on which S.B.A. was used during poor weather conditions by aircraft on operational flights:—

	No. 1 Group	No. 4 Group
*December 1942	49	118
October 1943	37	64
November 1943	65	52
December 1943	106	74

Number of occasions on which S.B.A. was used by aircraft on training flights:—

	No. 1 Group	No. 4 Group
*December 1942	240	172
October 1943	109	215
November 1943	65	254
December 1943	100	218

* At the time of the Inspector-General's investigation into the use of S.B.A. (A.M. File S.87187, Part II.)

the chief reason for the high accident rate then was the sudden deterioration of the weather at home bases, but was, however, requested by the Air Ministry to encourage further training and operational use of S.B.A., even though it was to be replaced eventually.[1]

A review of the S.B.A. programme had been planned for 1 July 1944, when the question of renewal of contracts was to be decided. At the end of February 1944 it was clear that, owing to delays in production of G.C.A. and the slow development of Eureka B.A. for use with Lucero, it would not be possible to supply Bomber Command with a substitute before the existing supply of S.B.A. equipment had been exhausted.[2] The Air Ministry informed Headquarters Bomber Command that the introduction of G.C.A. and B.A.B.S. would not be completed for eighteen months and that installation of S.B.A. equipment in all bomber aircraft would not be possible after about six months. Therefore, unless the S.B.A. contract were renewed there would be an interim period during which the command would have neither S.B.A. nor more than a limited number of G.C.A. sets. The renewal of large-scale S.B.A. production would seriously affect the production of other radar equipment and it was necessary to decide whether S.B.A. was an essential operational requirement for all bomber aircraft during the interim period.[3] At the beginning of May Headquarters Bomber Command decided that S.B.A. was to be removed immediately from aircraft of Nos. 1, 4 and 5 Groups. No. 3 Group would remove it during the interim period if necessary and Nos. 6 and 8 Groups would retain it until more modern aids were available. Headquarters Nos. 1, 4 and 5 Groups had decided that until B.A.B.S. was available, Gee would be used as a means of locating and approaching airfields. The interim use of Gee was considered a safe expedient, but it was an expedient and nothing more.[4] Such an arrangement would eke out the supply of S.B.A. and would not affect the production of radar equipment. Of the bomber training groups No. 91 Group wished to retain S.B.A. Installation on production lines of Lancaster, Halifax and Wellington aircraft was to be continued for as long as the equipment was available.[5]

In September 1944 an appreciation was made of S.B.A. ground installations. Commands were still reluctant to do without them before replacements were provided although less use was being made of them. In Bomber Command 50 installations were in operation and 11 were projected but it was estimated that these would be redundant in March 1945 when it was hoped 60 to 70 airfields would be equipped with B.A.B.S. Mark II. In Coastal Command 10 installations were in operation but these could be dispensed with when B.A.B.S. Mark IC (A.S.V. B.A.) became available, at, it was hoped, the end of 1944, although even then some S.B.A. installations would still be required for the use of diverted bomber aircraft. 11 installations were in operation and one was projected at airfields of the Allied Expeditionary Air Forces mainly for the use of diverted bomber aircraft, troop carrier aircraft, and glider tugs of No. 38 Group. It was estimated that the requirements would lapse by February 1945. In Transport Command six installations were in operation and four were projected; they

[1] A.M. File S.87187, Part II. No. 8 Group made extensive and successful use of S.B.A. operationally, mainly because the pilots were more experienced and it was the only group in which S.B.A. was installed at every airfield.

[2] A.M. File S.99682. [3] A.M. File S.87187, Part II. [4] A.M. File S.97074.

[5] A.M. File S.87817, Part II.

would not be needed when SCS.51 became available.[1] It was concluded that the total number of installations required was 103; at that time 105 S.B.A. ground installations were in service and 21 were under construction.[2]

Withdrawal of S.B.A. in 1945

Throughout the early months of 1945 the operational commands listed the airfields at which they no longer required S.B.A. If the installations were not required by another command which was willing to provide the necessary servicing personnel they were closed and the equipment recovered. Although not using it extensively Bomber Command was unwilling to discard S.B.A. until alternative systems were in operation. In February 1945 Headquarters Bomber Command requested the amendment of the original policy by which, in order to avoid duplication of approach systems, S.B.A. was to be removed immediately the installation of B.A.B.S. Mark II had been completed. It was considered necessary to retain S.B.A. at 48 airfields until all operational bomber aircraft were fitted with Lucero or Rebecca Mark VI.[3] This was agreed by the Air Ministry because the works services involved were not unduly extensive. At stations where simultaneous siting of S.B.A. and B.A.B.S. was impossible the removal of S.B.A. had to be accepted but normally it was reinstalled at an adjacent airfield, so that simultaneous operation of both equipments was possible and there was not a large gap in the S.B.A. cover. By March 1945 S.B.A. had been replaced in Coastal Command by B.A.B.S. Mark IC, except at five airfields, and was in operation at 18 Fighter Command airfields.

Plans were formulated for the almost complete withdrawal of the system. Flying Training Command was to continue the use of S.B.A. and radio track guides for instrument-flying training until they could be replaced, possibly in 1947, and Transport Command until SCS. 51 could be obtained from the U.S.A. In Bomber Command the number of ground installations was to be progressively reduced in phase with its decreasing use by aircraft until bombing operations against Germany were no longer required. The supply of aircraft equipment was to be constantly revised as other systems became available. By 1946 the changeover to B.A.B.S. had almost been completed. In April, 26 S.B.A. installations remained in the operational commands, 35 in Flying Training Command, and six at airfields used in emergency and by experimental aircraft and it was decided in the following month that S.B.A. equipments no longer required by the R.A.F. were to be transferred to the Ministry of Civil Aviation.

Radio Track Guides

S.B.A. beacon transmitters were used mainly as homing beams by pilots of bomber aircraft, and in March 1941 an extension of the system was suggested when Headquarters Bomber Command proposed that high-power beam beacons should be sited on the east coast of England for the use of aircraft returning from operations over Germany.[4] It was anticipated that the planned increase in the number of aircraft engaged on the bombing offensive would place

[1] A.M. File S.87817, Part II. [2] A.M. File CS.19083. [3] A.M. File S.87187, Part II.

[4] A plan to use them for target-location had been abandoned because range was too limited.

a severe and impracticable strain on the wireless direction-finding organisation, successful use of which, in any event, depended entirely on the continued serviceability after a bombing raid of aircraft W/T equipment.[1] In addition, it was hoped that use of a radio beam homing system might confuse the enemy radio intelligence to such an extent that unrestricted use of Gee, to be introduced into operational use the following year, might be prolonged before the inevitable jamming measures were started.[2] A trial installation of a high-power beam transmitter, similar to the main beacon used in S.B.A., was made at Cransford, near Southwold, in July 1941. The installation was static and its beam, 10 degrees in width, was directed towards Cologne. No. 3 Group was detailed to carry out trials, but all aircraft equipped with an S.B.A. receiver were encouraged to make use of the beam. The transmitter was within V.H.F. radio range of enemy-occupied territory so, in order to minimise the risk of jamming and the possibility of providing the enemy with an indication of the direction of attack, it was not switched on until the first aircraft were due to leave the target, and then only when the return route was via western Germany and the Low Countries. The beam could not therefore be used for navigation on the outward track and, because the alignment of the beam was fixed, its usefulness was strictly limited. Ranges of 100 to 150 miles were obtained, and although many pilots still preferred to use airfield S.B.A. installations, which in many instances happened to be on or near the homeward track, and which could be used for homing to base, its value and potentialities were clearly recognised. Three high-power beam transmitters were consequently installed at Cransford, Fulstow and Haine. The aerial systems were rotatable so that the beam could readily be aligned on any bearing to within an accuracy of less than 10 seconds of arc. The Cransford and Fulstow transmitters operated on a frequency of 36 megacycles per second and that at Haine on 36·4 megacycles per second, and the width of the beams was reduced to 1½ degrees. At each site an outer marker beacon was installed at a distance of approximately 50 yards from the main beacon. It transmitted continuously a beam identification letter, provided navigators with a pinpoint location of the beam, and enabled the risk of following the back beam to be avoided. The restriction preventing operation of the beams before aircraft left the target was removed, and crews were encouraged to make maximum possible use of the system for navigation both to and from the target. The beams were known as radio track guides or 'Jay' beams.[3] The Cransford beam (Jay beam 'B') was aligned on the main target whenever it lay eastward of England. The Fulstow beam (Jay beam 'C') was, as far as possible, aligned along the normal route to the main target followed by the aircraft of Nos. 1, 4 and 5 Groups if this was not through East Anglia. Care was taken to ensure that the two beams did not converge closer than 50 miles at a distance of 100 miles from Cransford. The Haine beam (Jay beam 'D') was aligned on Den Helder to intersect with the Cransford beam so providing a definite fix over the North Sea on the route to the target area. The alignment of beams 'C' and 'D' was given to navigators at briefing before an operation. The Jay beams provided good ranges, averaging about 350 miles to aircraft at 10,000 feet. The use of the beams to assist in target location did not in any way affect their value as homers, as they were kept in operation continuously

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[1] Bomber Command File BC/S.25857.

[2] A.H.B./IIE/70A. 'War in the Ether.'

[3] Bomber Command File BC/S.25857.

whenever bombing raids were in progress. Crews were briefed to keep just inside the beam, checking direction occasionally by flying to the edge, which was sharply defined, or to wander from one side of the beam to the other in an attempt to counteract the assistance given to the enemy for interceptions. Navigators found the beams of value because they could always obtain a position line which, combined with a D/F loop bearing, gave them a reasonably accurate fix. Crews soon began to make extensive use of radio track guides, and it was estimated that, by the end of March 1942, over 50 per cent of aircraft on bombing operations used the system. One disadvantage of the use of radio track guides for long-range homing was the additional strain it placed on a tired pilot in that he had to listen continuously to a monotonous signal.[1]

Throughout 1942 more beams were installed along the east coast of England, and in May Headquarters Bomber Command reported that although these beams were of value their usefulness was restricted by the limited arc through which the rotatable aerial system was effective and the unreliability of the back beam.[2] S.B.A. transmitters were also set up to act as track guides at Prestwick, Squires Gate, Silloth, and Valley for the benefit of aircraft flying across the Atlantic Ocean. The first three were directed at an M.F. leader beacon sited at Lough Erne. Aircraft homed to the leader beacon by using D/F loops and were then directed to an airfield, which they located by flying along the track guide. At the actual site of the S.B.A. transmitter a marker beacon was installed to indicate arrival at that point.[3]

In April 1944 a scheme was devised by Headquarters No. 26 Group and the Empire Central Flying School for the provision of a chain of radio track guides extending over the British Isles. It was aimed to provide navigational assistance for all aircraft equipped with S.B.A., particularly in areas where airfield concentration was greatest. Navigation to individual airfields from the tracks provided was to be made by dead-reckoning and with the assistance of local navigational aids such as beacons. The scheme was designed to fulfil three functions. First, to enable Flying Training Command aircraft to fly with safety in and above cloud and to provide a safe means of breaking cloud at any time during flight. This would permit training to be carried out in worse weather conditions than was then possible. At that time training was confined, with certain exceptions, to flights below cloud, because of the danger involved in breaking cloud without adequate radio navigational assistance. Secondly, to enable Flying Training Command to give more effectively the intensive training in cloud flying which was an urgent requirement and thus to raise the standard of instrument flying. Thirdly, to enable communication flights by aircraft not equipped with radar to be undertaken in safety when bad weather would normally make such flights impossible. The existing radio track guides, except the one between Hendon and Prestwick, formed no definite system of air routes, but when used in conjunction with the 130 approach beams installed at airfields they provided an almost continuous navigation system. The decision taken in November 1943 to discontinue gradually the use of S.B.A. in Bomber Command would reduce the number of S.B.A. installations and continuous guidance would not be available.

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[1] A.H.B./IIE/76A. [2] Bomber Command File BC/S.25857.

[3] A.H.B./IIK/54/1/7. Coastal Command Atlas of Aids to Navigation.

The scheme involved the establishment of eleven new radio track guides, the reorientation of three existing ones and the equipping of all Flying Training Command aircraft with S.B.A. At that date a maximum of six frequency channels was available on the S.B.A. receiver. This meant that five frequency channels could be used for the track guides, the remaining one being left for the local S.B.A. installation at the destination. Consequently track guides operating on the same frequency would need to be located 80 miles apart because of the danger of mutual interference, and the number that could be sited in any specific area was limited. A number of existing S.B.A. installations would have to be closed down because it was essential that radio track guides operated on high power. It was therefore proposed that the disposition of airfield S.B.A. installations should be replanned on a regional and geographical basis rather than on the existing basis of one per clutch of three airfields. It was assumed that a range of 120 miles at 2,000 feet would be available, 60 miles each for the front and back beams. Operation of the scheme required an adequate measure of control, and four methods were proposed. First, markers operating on track guide frequencies were to be placed at track intersections and at frequent intervals along the track. Secondly, markers were to be placed at all track guide transmitters for positive 'cone of silence' identification. Thirdly, speech beam facilities were to be provided on all track guides for broadcasting instructions to all aircraft simultaneously. Finally, a number of control points were to be instituted at regular intervals along all the track guides. They were normally to be at track intersections but common control was to be used where several intersections occurred near the same point. All the equipment required to implement the scheme was available. Only minor items needed to be manufactured and then only in small quantities. The number of personnel required to operate the scheme from sunrise to sunset was 40 exclusive of those required for controlling.

The Inspector-General of the R.A.F. was in favour of the scheme for he considered that S.B.A. could be of great value if used properly, and deprecated the increasing neglect of S.B.A. as an approach system by operational pilots of Bomber Command. In November 1944 the Director of Signals recommended its adoption but pointed out that frequencies could not be made available until the number of S.B.A. installations in the United Kingdom had been substantially reduced. In the meantime, however, it was possible for the installation of equipment to be started. The scheme met with some opposition, as it was considered that the use of M.F. radio ranges would meet the need. After investigation, however, it was decided that the use of M.F. radio ranges would not meet the cloud-flying training requirements of Flying Training Command and that the only short-term method of meeting them was the use of S.B.A., for three reasons. First, 50 per cent of Oxford aircraft had already been fitted with S.B.A. and enough equipment had been supplied to enable a complete installation programme to be made. Secondly, only 20 per cent of Oxford aircraft were equipped to use M.F. radio ranges and very few operators were trained in the use of the equipment. Thirdly, Transport Command needed M.F. radio ranges and the supply of equipment was inadequate to meet the requirement. The use of radio ranges by both Flying Training and Transport Commands would invite flying accidents. The Air Ministry, however, considered that the original scheme involved excessive expenditure in time and money and suggested that a smaller scheme incorporating the addition of one or two track guides to those already existing should be devised.

By January 1945 about 30 airfields in Flying Training Command had been equipped with S.B.A. and it had been decided to equip all Oxford, Anson, and Harvard aircraft with tunable S.B.A. receivers. A new radio track guide scheme was approved by the Air Ministry in June 1945. It involved the use of eleven radio track guides. The three major ones which formed the Hendon to Prestwick air route were to be made available to Flying Training Command when a new route on a different alignment had been provided, by means of M.F. radio ranges, for transport aircraft. Additional routes which intersected as many Flying Training Command beams as possible were to be provided by increasing the power of S.B.A. installations at Sealand, Church Broughton, Chipping Warden, Spitalgate, and Mona. The network was to be completed by the addition of three new radio track guides providing routes from Anglesey to Devon and from Devon to Hertfordshire. It was realised at the time of acceptance that the scheme was a short-term measure because even in Flying Training Command the use of S.B.A. was to be discontinued in 1947.[1]

V.H.F. Beam Approach

Fighter Command, in common with the other commands, required a beam approach system. S.B.A. ground equipment was installed at Fighter Command airfields, but only for the benefit of bomber aircraft in emergency; space limitation prevented the installation of S.B.A. receivers in single-engined fighter aircraft. Experiments in which use was made of the V.H.F. radio telephony equipment installed in fighter aircraft as a means of meeting the beam approach requirement were therefore initiated. Development along similar lines to provide a method by which enemy aircraft, equipped with jammers operating on a frequency band of 100 to 122 megacycles per second, could be intercepted, had already been started, and the system was suitably adapted.[2] The ground equipment consisted of one main beacon operating on frequencies from 100 to 124 megacycles per second, and two marker beacons operating on 360 megacycles per second. The aircraft R/T installation was modified so that the main beacon dot and dash signals could be received, and its output was used in conjunction with a diode detector, an audio-frequency amplifier and a separate aerial system for reception of the two marker beacon signals. No provision was made for visual presentation.[3]

In July 1941 arrangements were made for V.H.F. B.A. equipment to be installed in intruder, night-fighter, and day-fighter aircraft, in that order of priority. Ground installations were to be set up at each night-flying airfield and each sector airfield, with the intention that every sector should have at least one installation for day or night-fighter use.[4] By November 1941 one set of ground equipment had been produced and it was installed at West Malling for trials.[5] 13 operational and two training aircraft had been equipped, and eight operational pilots had been trained in the approach system.[6] The trials were successful and by the end of the year 69 ground installations had been ordered. The same difficulties were experienced as with S.B.A., and the rate of installation was very slow. The West Malling installation was moved to

[1] A.H.B./II/97/1/I. Radio Track Guides. Scheme for British Isles.

[2] Loop aerials were first used for homing, until their inherent disadvantages caused them to be discarded.

[3] Radio Aids to Air Navigation Committee Paper No. 2.

[4] A.M. File S.96994. [5] A.M. File S.67167. [6] A.M. File S.74991.

Bovingdon in January 1942 for special tests, and by the beginning of February 1942 two main beacon transmitters and two marker beacons had been delivered and were awaiting prototype approval by the R.A.E. An installation at Wittering was completed in March 1942 and by the end of that month No. 264 Squadron at West Malling, and the B.A.T. flight and one squadron at Wittering, had been fitted with the aircraft equipment. At the end of 1942 ten transportable V.H.F. B.A. ground equipments were in service and eight were in process of installation.[1]

In May 1944 Headquarters A.D.G.B. was asked to review requirements for V.H.F. B.A. in view of the fact that A.I. B.A. equipment was being made available. At the end of the month it was agreed that although there was no requirement for V.H.F. B.A. in single-engined day-fighter aircraft, it was still required in night fighters and in intruder aircraft; if, after trials, A.I. B.A. was found to be superior to or as good as V.H.F. B.A., the possibility of dispensing with the latter altogether was to be considered.[2]

[1] A.M. File CS.12820.

[2] A.M. File S.96994.

CHAPTER 17

BEAM APPROACH BEACON SYSTEM

The Beam Approach Beacon System was a combination of the principles of two existing radio systems, radar responder beacons and the *Lorenz* beam. An airborne interrogator transmitted pulse signals, on receipt of which the responder beacon retransmitted dot and dash signals by means of two aerials to the right and left of the runway, the power being switched alternately between the two aerials. The signals overlapped to form the beam, an equi-signal zone in the centre, which was aligned along the centre of the runway to form the approach path. The signals were received by the airborne apparatus and displayed on a cathode ray tube. The operator obtained information from the CRT display of the position of the aircraft in relation to the beam because the beam transmission was so arranged that the strength or amplitude of the pulses increased as the beam was approached. Continuous range information was derived from a measurement of the time taken by the pulses to make the double journey at the known and constant speed of radio waves. The first B.A.B.S. equipment was devised early in 1941 at a Coastal Command station in Northern Ireland. An I.F.F.-type beacon based on the A.S.V. homing beacon was used with A.S.V. Mark II as an airborne interrogator. An improved version was built by the Telecommunications Research Establishment, which also designed a version for Fighter Command for use with A.I. A.S.V. B.A. was adopted for Coastal Command and A.I. B.A. for Fighter Command, and installation proceeded slowly throughout 1943 and 1944. There were some serious faults in this early system, B.A.B.S. Mark I as it was later designated, but it proved a useful approach aid in both Fighter and Coastal Commands.[1] In 1943 a Bomber Command requirement arose for B.A.B.S. to be used in conjunction with Lucero; insufficient range was obtained with B.A.B.S. Mark I. Development began at the Telecommunications Research Establishment in 1943 of B.A.B.S. equipment operating on a wide frequency band, using Eureka as the ground beacon and Lucero or Rebecca as the aircraft interrogator. Many of the faults of the older version were eliminated; in particular the aerial system was much improved. It transmitted on the Bomber Command frequencies of 214 to 234 megacycles per second. Successful trials were held at the beginning of 1944 and in the autumn of that year it was decided that the new system should be adopted as the main approach aid for Bomber Command. A large-scale programme was initiated. During experimental work the equipment was known as Eureka B.A., later as Lucero B.A., and in June 1944 the name was changed to B.A.B.S. Mark II. A mobile version, known as B.A.B.S. Mark IIM, and an air transportable version, B.A.B.S. Mark IIA, were also developed. B.A.B.S. Mark II was easily modified to operate on Fighter Command frequencies, 190 to 196 megacycles per second, and this version was called B.A.B.S. Mark IIF, while the Fighter Command mobile version was referred to as B.A.B.S. Mark IIFM. Installation of this equipment had not proceeded far by the end of the war because of the slow rate of production.

[1] A.S.V. B.A. became B.A.B.S. Mark IC, and A.I. B.A. became B.A.B.S. Mark IF, in 1944.

Early Development of A.S.V. B.A.

The first use of A.S.V. beacons as a beam approach system was made in February 1941 at Limavady in Northern Ireland where No. 502 Squadron was stationed. A method of using A.S.V. homing beacons for beam approach, employing the *Lorenz* principle of interlocking dot-dash signals to form an equi-signal zone, was devised by Mr. Hinkley of the T.R.E., signals officers at the station, and certain pilots of No. 502 Squadron who showed exceptional interest in the homing beacon.[1] Its obvious advantage over S.B.A. lay in the fact that the pulse system gave continuous range information. At Limavady a one-degree beam was produced by the use of two five-element Yagi aerials taken from a Wellington aircraft and the output of an I.F.F. set was switched on to each aerial in turn but for different time periods.[2] Reports of the use of an A.S.V. beacon as a beam approach aid were given to the Air Ministry, Ministry of Aircraft Production and the T.R.E. by a member of the staff of the Radio Department, R.A.E., after a visit to Limavady in February and March 1941.[3]

On 18 March 1941 Mr. A. P. Rowe, Superintendent of the T.R.E., obtained authority from the Ministry of Aircraft Production to begin a programme of research into the use of A.I. and A.S.V. beacons for blind approach. By May of that year sufficient progress had been made, and sufficiently promising results achieved, to warrant operational trials at the Coastal Command Development Unit at Carew Cheriton, which were held in June 1941.[4] The experimental model was then given trials at Abingdon so that its performance might be compared with that of S.B.A. At a meeting at the Ministry of Aircraft Production on 25 July 1941 the official opinion expressed on the system was that, as it stood, it was no better than S.B.A., but it was cheap and mobile and was a potential requirement for Coastal Command airfields, most of which were not equipped with S.B.A.[5] At this meeting it was recommended that the new system should be tested at a Coastal Command station in Service conditions. Limavady was chosen and later trials were also held at Wick and St. Eval. Headquarters Coastal Command had to rely on the resources of the T.R.E. for the provision of the necessary equipment for the trials because no contract could be placed with a radio firm until specific requirements could be formulated. It was therefore agreed that the T.R.E. should manufacture three sets of aerials operating on 176 megacycles per second and two more sets operating on 214 megacycles per second. The first T.R.E. experimental model had operated on the latter frequency.[6]

The interim A.S.V. B.A. system developed by the T.R.E. was a modified version of I.F.F. Mark IIG used in conjunction with A.S.V. Mark II.[7] The ground equipment consisted of two A.S.V. beacons, the first of which was the homing beacon and the second the approach beacon. The homing beacon was similar to those already in use in Coastal Command and was used in conjunction with an aerial system giving a horizontally polarised radiation pattern. The homing beacon worked on a fixed radio frequency, that of A.S.V., and its output was coded for recognition purposes. An I.F.F. Mark IIG set was installed in a 10 cwt. van and two Yagi aerial arrays with a switch box were mounted above

[1] M.A.P. File SB.2456. [2] T.R.E. Report No. T.1740. [3] M.A.P. File SB.2456.
[4] M.A.P. File SB.18841. [5] A.M. File CS.18619. [6] M.A.P. File SB.18841.

[7] *See* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception', for details of I.F.F., and Volume VI: 'Radio in Maritime Warfare', for details of A.S.V.

the roof of the van.[1] The I.F.F. set was modified to work on a single fixed radio frequency and the coding mechanism was put out of action. The approach beacon operated on a radio frequency 2½ megacycles per second higher than that on which the A.S.V. transmitter and the homing beacon worked. This had the effect of reducing possible confusion due to the two beacons operating in close proximity and also reduced interference from ground echoes, enabling the approach beacon signal to be received and observed free of interference. The Yagi aerials were four director arrays mounted on a light wooden framework above the roof of the van so that they could be folded for travelling and extended for use. When extended the longitudinal axes of the aerial arrays were inclined 25 degrees to the fore-and-aft axis of the van, one being inclined to the left and the other to the right. The switch box contained the feeder network, and a motor-driven cam enabled the output of the I.F.F. aerial system to be switched to each aerial alternately. The aerials were symmetrically arranged so that they radiated one to one side of the approach heading and the other to the other side. The aerial that covered the left-hand side of the approach, looking downwind, was energised for approximately two seconds with about half-second intervals, and the aerial that covered the right-hand side was energised for approximately half a second with two-second intervals, so that they interleaved. This gave a two-second dash sector to the left, a half-second dot sector to the right, and a steady continuous equi-signal path in the middle. The equi-signal path was arranged to lie along the approach course. The aerials were so mounted on the motor vehicle that the equi-signal path was along the fore-and-aft axis of the vehicle, shooting forward. The vehicle containing the approach beacon was placed at the upwind end of the runway, with the fore-and-aft axis pointing straight down it. The beacon was switched on only when aircraft were landing.[2]

The homing beacon, the effective range of which was about 75 miles, was used to home aircraft from a distance to within about one mile of the beacon. Pilots were provided with continuous information on the A.S.V. display of the direction and range of the beacon. When within one mile R/T communication was established with airfield control so that landing instructions and barometric pressure information could be obtained. Aircraft were then flown away from the airfield on the reciprocal of the approach heading for a distance of five or six miles. The distance flown from the airfield was indicated on the A.S.V. display by means of the backward radiation from the A.S.V. aerials; this was not great but was enough for a range of a few miles. When at a distance of approximately six miles from the airfield aircraft turned on to the approach heading and the A.S.V. receiver was tuned from the frequency of the homing beacon to that of the approach beacon.

When the A.S.V. operator received signals from the approach beacon he informed the pilot of the range of the aircraft from the beacon; this range was given continuously by the position of the approach beacon signal on the time-base scale of the A.S.V. indicator. The A.S.V. operator continued to give the pilot range readings every half-mile until a range of two miles was indicated, after which a reading was given every quarter-mile. The A.S.V. operator also observed whether dots or dashes were reproduced on the display, and this information was also passed to the pilot. If dots only, or dashes and dots with

[1] The Yagi aerial array was a directional aerial system.

[2] M.A.P. File SB.18841.

dots predominating, were received, the aircraft was to the left of the approach path, and if dashes only, or dashes and dots with dashes predominating, were received, then the aircraft was to the right of the approach path. The A.S.V. operator informed the pilot of any deviation from the equi-signal zone and the pilot then made the necessary corrections to regain it. By the dot-dash indications and the range and altimeter indications the pilot was able to fly his aircraft over the boundary of the airfield at the correct height and heading straight towards the runway. The final hold-off and touchdown was done visually and it was emphasised by the T.R.E. from the beginning that A.S.V. B.A. was a blind approach, not a blind landing, aid.[1]

The advantages of this method of approach were many. It required very little additional equipment in aircraft already fitted with A.S.V. There was a great measure of secrecy because the A.S.V. beacon did not radiate continuously but only when interrogated by A.S.V.; security was also ensured by the fact that the signals from the ground could not be received by continuous-wave wireless equipment. The method of approach was much easier than that used with S.B.A.; range indication was continuous whereas with S.B.A. it was only available when the aircraft passed over the marker beacons.

In November 1941 Headquarters Coastal Command stated that trials of A.S.V. B.A. indicated that it fulfilled operational requirements, and they requested provision of 168 fixed and 28 mobile beacons with aerials for installation at landplane stations.[2] The Air Ministry approved the provision of A.S.V. B.A. equipment for Coastal Command airfields but considered it to be an impracticable system for any command in which aircraft were not already fitted with A.S.V. because of the weight and complication of the aircraft equipment.[3] In December 1941 a development contract was placed with the firm of Murphy Radio for six final-type A.S.V. B.A. sets. Various modifications found necessary as a result of experimental work at the T.R.E. and of the Coastal Command trials were incorporated. The R.A.E. was appointed the supervisory design authority in conjunction with the T.R.E. In the meantime, the T.R.E., in response to a request from Headquarters Coastal Command, agreed to construct further interim-type A.S.V. B.A. installations from I.F.F. Mark IIG because of the urgent need within the command for adequate beam approach coverage. By March 1942 five such sets had been made, all of which were in operational use.[4]

In January 1942 Headquarters Coastal Command reported that trials had been carried out with two methods of beam approach for flying-boats. The first consisted of homing over a beacon installed in a launch, sited at the downwind end of the safe landing area, and the second of landing along a beam, the beacons being sited on the windward shore. Both methods were considered superior to S.B.A. and an operational requirement for A.S.V. B.A. for flying-boat bases was raised.[5] At a meeting of the Radio Aids to Air Navigation Committee held at the end of January 1942 Headquarters Coastal Command repeated its belief that A.S.V. B.A. was preferable to S.B.A. and agreement was therefore reached that the necessary modifications to aircraft radar equipment to enable beam approach procedure to be followed should be permitted in all Coastal Command aircraft.[6] In March 1942 the Air Ministry obtained

[1] M.A.P. File SB.18641. [2] A.M. File CS.18618. [3] A.M. File CS.18619.
[4] M.A.P. File SB.18641. [5] A.M. File CS.18819. [6] A.M. File CS.18818.

authority from the Treasury Inter-Service Committee for the provision of beam approach facilities at 43 landplane and 17 flying-boat stations in Coastal Command, and a production contract for 163 final-type A.S.V. B.A. installations was placed with the firm of Murphy Radio.[1]

Development of Final-Type A.S.V. B.A.

Development of the final-type A.S.V. B.A. was undertaken by the firm of Murphy Radio under the supervision of the T.R.E. and the R.A.E. In place of the I.F.F. Mark IIG set, which had been used in the experimental stages, the A.S.V. homing beacon was adapted for beam approach purposes. This homing beacon employed the I.F.F. principle and was found readily adaptable for the approach role because it required only the addition of an aerial switch unit to provide the interlocking dot and dash signal path. The transmitter/receiver unit and the AC power unit of the homing beacon were retained but the coding unit was replaced by a battery-driven power unit embodying a rotary convertor and an aerial switching unit.[2] The receiver received pulses from the aircraft interrogator, amplified them and caused them to trigger the transmitter. This radiated energy in two broad diverging beams. Power was fed into the aerials alternately so that one aerial radiated for a period of 0·2 seconds and the other for the succeeding period of 1·2 seconds, the cycle being repeated indefinitely as long as interrogator pulses were received from the aircraft. The aerial which radiated for the shorter period was called the dot aerial. Viewed from the aircraft during an approach the dot zone was on the left and the dash zone on the right. The aerials were so arranged that the runway lay in the zone in which the signals from both aerials were, so far as the approaching aircraft was concerned, of equal strength. If the aircraft was on the right path to the airfield signals of equal amplitude were received from each aerial. The aerial switching was effected by means of a Post Office Type 3000 relay with two changeover contacts. Stub-line switching was chosen rather than straight changeover switching in order to reduce to a minimum power going into the wrong aerial. The transmitting aerials consisted of two identical six-element Yagis (reflector, folded dipole and four directors) mounted on a framework on top of the beacon.[3] A super-regenerative receiver was used. The beacon operated on a frequency of 176 megacycles per second. In the early days of its development and use the apparatus was referred to as A.S.V. B.A. or A.S.V. B.A.B.S., the code name B.A.B.S. Mark IC, which was given to it later, not being generally used until 1944.[4] When the first model underwent experimental tests at the firm it was found to be unsatisfactory in that it was very susceptible to load variations. It was decided in November 1942 that the superheterodyne principle, as used in A.I. B.A., then undergoing development at the same firm, should be incorporated in the transmitter/receiver unit of A.S.V. B.A.[5]

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[1] M.A.P. File SB.18641. The estimated cost was £100,562.

[2] M.A.P. File SB.18641.

[3] SD.0245(2). Beam Approach Beacon Systems.

[4] When referring to the radar beacon system of beam approach in general, as opposed to a particular version for any one command, the terms B.A.B.S. or radar B.A.B.S. were used, especially when Fighter Command adopted the Coastal Command system and needed a description for it.

[5] M.A.P. File SB.18641.

Early Development of A.I. B.A.

The use of I.F.F. beacons for beam approach with A.I. was begun in the early summer of 1941 by No. 604 Squadron at Middle Wallop, with beacons made locally from I.F.F. Mark IIG.[1] This was known as the two-beacon system and was installed at various Fighter Command airfields during 1941.[2] During that year three schemes based on this principle were developed in Fighter Command but the system was merely an interim measure because it was primarily designed for use with A.I. Mark IV. Meanwhile the T.R.E. developed a beam approach system for Fighter Command which was based on the B.A.B.S. method adopted by Coastal Command. In October 1941 the Telecommunications Flying Unit at Hurn began arrangements for testing the various A.I. B.A. systems developed by the T.R.E. and Fighter Command to find out which was most suited to operational use within that command. The main systems developed were five in number, three using the two-beacon system and two being based on the Coastal Command system. The three versions of the two-beacon system differed among themselves chiefly in the positioning of the beacons on the airfield.[3] Two different versions of the radar beam system were built by the T.R.E. for Fighter Command and were installed at the T.F.U. Hurn for comparative trials with the other methods in January 1942. One of the models used a battery-driven I.F.F. beacon which fed two independent wire-netting corner aerials through a stub switching arrangement driven by a multi-vibrator. This did not give a satisfactory performance. The other used a beacon constructed from modified I.F.F. Mark IIG and an aerial system comprising two Yagi arrays set at an angle of 25 degrees and separated by a wire-netting sheet. The whole structure was mounted on a wooden framework measuring approximately 10 feet by 6 feet at the base and 10 feet high. A mechanical switching arrangement was incorporated giving dots of ⅛ second and dashes of 1⅞ seconds' duration. It radiated on 190·5 megacycles per second. This system worked well with A.I. Mark IV, could be made to work with A.I. Mark V if certain modifications were incorporated, but did not work with Mark VI.[4]

In January 1942 the T.F.U. Hurn made flight tests of the five approach systems, using A.I. Marks IV and V in Anson, Blenheim, Havoc and Beaufighter aircraft.[5] In February 1942 aircrew from the Fighter Interception Unit at Ford and from Nos. 29 and 219 Squadrons visited Hurn and participated in trials.[6] At a meeting at Hurn on 25 February 1942 Headquarters Fighter Command representatives, together with pilots who had participated in the trials, discussed the different approach systems and agreed that the B.A.B.S. system was preferable to the two-beacon system. It was a satisfactory method with an average pilot and operator in conditions of 300 feet cloud-base and 800 yards horizontal visibility.[7] It was recommended that the method should be adopted for Fighter Command but, before stating a definite requirement, Headquarters Fighter Command wanted to hold Service trials at West Malling and requested the provision of equipment for that purpose. The T.R.E. agreed to manufacture the equipment although it was unable to supply more than two

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[1] For details of A.I. *see* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

[2] M.A.P. File SB.18841.

[3] M.A.P. File SB.30209.

[4] M.A.P. File SB.18841, Part II.

[5] M.A.P. File SB.30209.

[6] M.A.P. File SB.18841, Part II.

[7] M.A.P. File SB.30209.

aerial systems and one beacon. The trial installation was set up in June 1942 at West Malling where aircrew of No. 29 Squadron carried out trials.[1] At first operation of the experimental beacon was not satisfactory, the chief complaints being that the edge of the pulse was ragged and that the signal faded too rapidly beyond six miles at 1,000 feet. An expert from the T.R.E. was sent to investigate the faults and as a result of modifications effected by him performance was improved.[2] In the late summer of 1942 Headquarters Fighter Command complained of beam shift but by October 1942 T.R.E. modifications, consisting of the incorporation of a new type of aerial and strengthening of the concrete bases, appeared to have eliminated the fault.[3] Twenty hours' flying, mainly in daylight, was carried out with the improved experimental A.I. B.A. equipment, and pilots considered its performance to be satisfactory. There was one suggestion that marker beacons should be introduced to improve the range accuracy but the T.R.E. considered this provision would be unnecessary when the unstable time-base of A.I. Mark IV had been eliminated. The installation was moved to Church Fenton in December 1942 for continuation trials and experimental work. Complaints were again received of beam shift, particularly noticeable during wet weather. In December the entire responsibility for research and development of B.A.B.S. was entrusted to the R.A.E. and experts from that establishment were sent to investigate. The problem was solved by the placing of celluloid cones over the aerial arrays for protection against rain and by the middle of February 1943 the performance of the system was considered satisfactory by Headquarters Fighter Command.[4]

A development contract for six A.I. B.A. installations had been placed with the firm of Murphy Radio in December 1941 at the same time as that for A.S.V. B.A. It was then impossible to draw up any production contract because no operational requirement had been stated.[5] However, at a meeting of the Radio Aids to Air Navigation Committee on 13 January 1942 Headquarters Fighter Command raised an operational requirement for the provision of A.I. B.A. at all night-fighter airfields, subject to the outcome of Service trials being satisfactory.[6] At the end of March 1942 the Ministry of Aircraft Production urged that Headquarters Fighter Command should state a definite and formal requirement, particularly as the Service trials at West Malling in the preceding months had shown that B.A.B.S. was operationally suitable for the command. This requirement was needed so that financial authority might be sought and a production contract placed in time to prevent a serious gap between the completion of development work and the commencement of main production. In April 1942 Headquarters Fighter Command stated that A.I. B.A. was required at 50 airfields, possible overseas demands being included in the estimate. The initial supply of equipment per site was the same as for Coastal Command, namely six aerial arrays, three beacons, two huts and one van. Treasury approval was given in June 1942 and a production contract for 150 equipments was placed.[7]

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[1] A.M. File CS.16919.

[2] M.A.P. File SB.30209.

[3] M.A.P. File SB.18641, Part II.

[4] A.M. File CS.18618.

[5] M.A.P. File SB.18641, Part II.

[6] A.M. File CS.18618.

[7] A.M. File CS.18618. Total estimated cost was £135,000.

Development of Final-Type A.I. B.A.

The A.I. homing beacon was not adaptable for beam approach work so the final type of A.I. B.A. beacon, TR. 3137, was specially developed from the A.S.V. B.A. beacon. It consisted of a transmitter/receiver unit incorporating a superheterodyne receiver, the same AC power and battery-driven units as used in A.S.V. B.A., and an aerial switching unit similar in design and purpose to the A.S.V. B.A. unit but differing in that it incorporated a co-axial cable. The system was housed in a cabinet type of rack. In the development models provision was made to include variable delayed pulse facilities so that the delay on each beacon could be adjusted to suit the runway on which it was operating and so give the homing aircraft a distinct indication of the beginning of the runway. With this feature, the beginning of all runways fitted with the equipment gave a consistent time-base indication to an accuracy of approximately 200 yards.[1] The final type A.I. B.A. was later given the code-name B.A.B.S. Mark IF.

The differences in the construction of the radar beam approach systems developed for Fighter and Coastal Commands resulted from the fact that they were interrogated by different aircraft installations. A.S.V. B.A. was tuned to a fixed frequency of 176 megacycles per second to respond to A.S.V. Mark II while A.I. B.A. operated on a frequency of 193 megacycles per second to work in conjunction with A.I. In the final-type A.I. B.A., aerial system Type 150, consisting of three corner aerials, was used. It was omni-directional, providing 360 degrees of coverage, and vertical polarisation was found to be the most suitable. In A.S.V. B.A., the Type 151 aerial system, using three Yagi aerial arrays, was employed. The aerials were partially directional, with coverage in the horizontal plane of approximately 120 degrees, and horizontal polarisation was used because it resulted in less interference being experienced from sea returns. Both types of approach beacon had an effective range of 10 to 15 miles.[2]

Production of B.A.B.S. Mark I

Work on the development contract for A.S.V. B.A. beacons began in December 1941 and on that for A.I. B.A. beacons in March 1942.[3] A contract for the production of aerial systems for both approach beacons was placed with the firm of Dynatron.[4] As no technical development was required and as there was no shortage of components, production of the aerial systems was fairly rapid and was soon in advance of that of the beacons. Work on the beacons was still largely experimental and even after the contracts were placed and financial authority given, progress was considerably slowed down, both by the shortage of component parts and by various technical problems that required solution. In March 1942 the Ministry of Aircraft Production estimated that the first A.I. B.A. development model would be completed by the end of April and the other five would be ready by mid-July if no major modifications were required as the result of prototype tests. The first setbacks to production occurred through the shortage of components. In May 1942 it was reported that a hold-up in the supply of condensers was causing delay and in June the shortage of rack cabinets had the same effect.[5] To overcome these troubles

[1] M.A.P. File SB.18641, Part II.
[2] M.A.P. File SB.18641, Part II.
[3] M.A.P. File SB.18641, Part II.
[4] A.M. File C.18192/44.
[5] M.A.P. File SB.18641, Part II.

the Ministry of Aircraft Production increased the priority of both items. In August 1942 unexpected technical difficulties were encountered by Murphy Radio in the production of aerial switching units. As the accuracy and safety of the system depended so much on the correct functioning of this part of the equipment the Ministry of Aircraft Production ruled that no attempt was to be made to relax the design requirements in order to keep to the production dates originally forecast. As a result of the difficulties the Ministry of Aircraft Production forecast that the main production of A.S.V. B.A. was not likely to start until the end of October 1942 and that of A.I. B.A. before the end of February 1943.

A further delay in the production of A.S.V. B.A. occurred in September 1942 when it was found, on testing the development model, that the super-regenerative receiver worked unsatisfactorily. On 6 October 1942 it was decided to use a superheterodyne receiver as in A.I. B.A.[1] This setback meant that development and production of A.S.V. B.A., which had previously been ahead because of the earlier trials and stated operational requirement, fell behind that of A.I. B.A. Earlier it had been hoped that A.S.V. B.A. would be available fairly soon after the contract had been placed because it required very little development from the A.S.V. homing beacon whereas A.I. B.A. was an entirely new design. This unexpected delay caused much concern in Coastal Command, where a radar approach aid was required for training and operational use in the winter of 1942/43. In order to meet the urgent need the Ministry of Aircraft Production suggested to the Air Ministry that, as an interim measure until type approval was given and production of the final system begun, beacons based on I.F.F. Mark IIG should be used. The proposal was agreed and the firm of Dynatron was asked to supply 20 interim-type beacons. Coastal Command personnel were to be responsible for installation, and for making the aerial systems with the assistance of drawings from the R.A.E.

Research and development continued, both at the contractors and at the research establishments. A satisfactory design for the aerial switch unit was produced by the R.A.E. in February 1943. In order to speed the production of B.A.B.S. the R.A.E. agreed to release a technical officer to work at Murphy Radio in close co-operation with the contractor's technicians in order to make sure that, as the design progressed, development could immediately be approved by the R.A.E. At that date one A.I. B.A. development model had been given provisional type approval and it was hoped that the remaining five A.I. B.A. and six A.S.V. B.A. equipments would be completed and type-approved by the beginning of March 1943. In April 1943 the Ministry of Aircraft Production estimated that production models of B.A.B.S. would be manufactured at the rate of five per week from the end of August 1943. On 15 April 1943 the programme was given a higher priority in order to avoid further delay. Additional measures to speed production were taken in June, after type approval had been given to A.S.V. B.A. They included raising the priority of outstanding components needed for B.A.B.S., raising the priority of and increasing the effort expended on the erection of suitable buildings, hard standings and supply cables to the runway sites, and applying the highest priority to the supply of vehicles.[2]

[1] M.A.P. File SB.18641, Part II.

[2] M.A.P. File SB.18641, Part II.

In spite of these efforts to increase production the Air Ministry had again to ask, in June 1943, for a further supply of modified I.F.F. Mark IIG, this time 25, in order to ensure that the use of B.A.B.S. facilities in Coastal Command could be continued until the main B.A.B.S. production models were available. The slow production of B.A.B.S. was causing acute concern, both at Headquarters Fighter Command and at Headquarters Coastal Command. The decision to adopt A.S.V. B.A. in place of S.B.A. had been taken on the understanding that it would be provided by the winter of 1942/43. The existing A.S.V. B.A. ground equipment was a temporary measure and provided only training facilities. It did not meet operational requirements for bad weather landing. In June 1943 the Commander-in-Chief, Coastal Command complained forcibly to the Air Ministry about the apparent lack of progress made with the production programme. '. . . I find it difficult to persuade myself that it has been handled with the energy and determination that its importance warrants. I need not remind you of the repeated attempts to increase the numerical strength of Coastal Command at the expense, usually, of the bombing offensive. At the same time we are complacently accepting a state of affairs in which the lack of a relatively simple article of equipment, asked for 19 months ago, is reducing the operational capacity of the command by the equivalent of several squadrons by making it impossible to operate in weather which, with adequate A.S.V. B.A. facilities, should be no bar to flying. . . .'[1] The Air Ministry stated that strenuous efforts were being made and a Beaconry Working Sub-Committee had been formed which was responsible for reviewing in detail the Coastal Command requirement for A.S.V. homing and beam approach beacons and for implementing the policy to provide the facilities by the autumn of 1943. At the same time questions were raised about the delay in the A.I. B.A. installation programme. At the 2nd meeting of the Night Air Defence Committee on 24 June 1943 the Air Ministry was asked to investigate the delay in the provision of A.I. B.A. at airfields used by night fighters. In the following month the Air Member for Supply and Organisation submitted a report on the B.A.B.S. programme. He stated that, in the first place, the design and development of a satisfactory beacon had been slow, partly because of the large number of defects experienced with the experimental models, partly because of the division of responsibility for research and development between the T.R.E. and the R.A.E. and partly because of the lack of enthusiasm for that type of navigational aid in the squadrons which conducted the early tests.[2] Secondly, A.S.V. B.A. was given a higher priority of production than A.I. B.A. because V.H.F. B.A. was being developed and produced for Fighter Command. Finally, installation plans had been made which involved building effort outside the scale available and lack of the necessary labour and materials made a change in plans necessary at a later date.[3]

When the development models of both versions of B.A.B.S. Mark I had been approved in April 1943 one of each was allocated to the contractors to serve as prototypes for main production, one of each to the R.A.E. for development purposes, and the other four of each type to airfields chosen by Headquarters Coastal and Fighter Commands. The former permitted one of their instal-

[1] A.M. File CS.18618.

[2] R.A.E. experts attributed many of the fundamental faults in the early B.A.B.S. equipment to the unsatisfactory early division of design authority whereby the T.R.E. was responsible for research and the R.A.E. for engineering. (M.A.P. File SB.18641, Part II.)

[3] A.M. File CS.18618.

lations to be transferred to the R.C.A.F. and one to the Royal Navy for experimental work. Colerne, Middle Wallop, Chivenor, and St. Eval were the first operational airfields selected as locations for B.A.B.S., and the other two A.I. B.A. equipments were installed at Ford and Hunsdon.[1]

With the installation and operational use of the B.A.B.S. development models certain technical faults quickly became apparent particularly in the A.I. B.A. version. Chief among them were frequency-pulling, rapid pulse amplitude modulation, and frequency modulation over the pulse width. Frequency-pulling, a change of frequency with aerial switching, was caused by the difference in reactance of the aerials, and was especially noticeable when B.A.B.S. was interrogated by A.I. Mark VIII. Then, because the interrogator was not very sensitive, it was necessary to get as much power as possible from the beacon transmitter by tight coupling, but this was difficult to achieve without frequency-pulling and pulse-distortion. The use of trimming condensers to balance the reactance was not sufficient. The fault caused incorrect indications to be received in the aircraft. It was considered by the R.A.E. that the only remedy possible was to employ looser coupling for the transmitter thus reducing the range of B.A.B.S. with A.I. Mark VIII to five miles. The T.R.E. also thought it might be necessary to accept a shorter range, or to abandon altogether the use of A.I. Mark VIII for radar beam approaches. In November 1943 the problem was partially solved when Headquarters Fighter Command stated that there was no operational requirement for B.A.B.S. with A.I. Mark VIII.[2] Amplitude modulation caused a fluttering of the top of the pulse which masked the observation of small keying changes and resulted in degradation of the beam width. The R.A.E. evolved a means to secure freedom from amplitude modulation by modifications of a comparatively minor nature. The amount of frequency modulation experienced was dependent on the extent of freedom from frequency-pulling so that the solution of the former problem rested with that of the latter.[3] By the middle of December 1943, as a result of the various modifications incorporated in an installation located at the Fighter Interception Unit, Ford, performance was much improved. A mechanical change enabled both transmitter aerials to be swung as one unit above a common pivot; the production-type radiators were used for the first time and these were joined to their lead feeder by a polythene moulding; an adjustable tap in the switch unit enabled the selection of one of three speeds of keying; modifications to the TR unit had eliminated variation in the size of the outgoing RF pulses; the coupling between the output coil and the tank circuit of the oscillator was decreased in order to reduce the magnitude of frequency-pulling between aerials. Arrangements were made in December 1943 for the modifications to be incorporated in the production models being built by Murphy Radio. Main production had been stopped pending the result of R.A.E. investigations, but was recommenced as the technical troubles were cleared.[4] At a meeting of the Beaconry Working Sub-Committee on 15 December 1943 it was stated that adequate supplies of components were available for modifications to be made, both on the production line and retrospectively.

An A.I. B.A. development equipment was installed at Hunsdon in September 1943, and was regarded as being the prototype B.A.B.S. Mark IF installation for

[1] A.M. File CS.18618.
[2] M.A.P. File SB.18641, Part II.
[3] M.A.P. File SB.18641, Part II.
[4] A.M. File CS.18619.

Fighter Command. The F.I.U. carried out check flights with various marks of A.I. Results were not satisfactory and it was transferred to Ford for intensive trials. Performance continued to be unsatisfactory but as work to eliminate technical faults was still in progress on the other equipment at Ford, it was decided that an installation programme of the equipment as it stood should be started in Fighter Command, and necessary modifications incorporated retrospectively, in order to hasten the provision of B.A.B.S. However, in October 1943 it was decided that the Hunsdon model should be sent to Defford for incorporation of such modifications as had already been devised by the R.A.E. It was reinstalled at Ford on 17 December 1943 where further trials took place. Apart from the first three runs after installation, when the beam was well off the runway, all approaches were satisfactory. Aircrews commented favourably on the definition and width of the beam. The conclusion reached was that the A.I. B.A. beacon was operationally acceptable for beam approach when A.I. Marks IV and V were used.[1]

Meanwhile quantity production of A.S.V. B.A. had also been stopped whilst investigation into technical faults proceeded. The difficulties experienced with this equipment were not so serious as those encountered in its Fighter Command counterpart although some of the development models of A.S.V. B.A. were prone to frequency-pulling and pulse jitter. In August 1943 the development installed at St. Eval was temporarily transferred to the B.A.T. Flight at Leuchars.[2] The R.A.E. incorporated the modifications necessary to remedy shortcomings which had been disclosed and arranged for a supply of components to enable the other development models to be modified. In October 1943 it was reported that preliminary trials of the installation showed very good results. This model was designated as the prototype for No. 26 Group installation in Coastal Command. Arrangements were made for the B.A.B.S. Familiarisation Party from the Signals Development Unit at Hinton-in-the-Hedges to conduct flight acceptance trials, from which a standard of acceptance was evolved for future installations in Coastal Command. By the middle of December 1943 the R.A.E. investigation into technical faults was completed and new designs were cleared. Production was recommenced and final type approval was given on 3 March 1944.[3]

Installation Procedure

Preparatory plans for the installation of B.A.B.S. Mark I at airfields in Coastal and Fighter Commands had been made and Headquarters No. 26 Group was made responsible for siting and installation with help from the R.A.E. in the early stages. Selection of sites was made in the first place by No. 26 Group. Each site was then visited by representatives of the user command and tested with an interim B.A.B.S. equipment. By the end of March 1943, sites had been selected and approved at five airfields in each command.[4]

It was agreed in June 1942 that each airfield selected should be provided with a permanent installation on the runway most frequently used and with aerial systems for use only with mobile B.A.B.S. on other runways, and instructions to that effect were issued by the Air Ministry to the Air Ministry

[1] A.H.B./II/54/93(A). F.I.U. Report No. 228.

[2] M.A.P. File SB.18641, Part II.

[3] M.A.P. File SB.18641, Part II. Installation of 18 B.A.B.S. Mark IF equipments had been completed by April 1945. In July 1945 B.A.B.S. Mark IF was declared obsolete.

[4] A.M. File CS.18618.

Works Department in August 1943. Four aerial systems and concrete plinths were to be installed at each airfield but power supply was to be provided only to the permanent site, about 170 yards from one end of the preferred runway. Both the R.A.E. and Headquarters No. 26 Group opposed this policy on the grounds that it was unsatisfactory since an equipment which had been correctly aligned on a site was unlikely to work well after removal and replacement. Changes in electrical performance of the feeders were probable, especially during damp weather, with a possible deviation of the beam from the runway. The original scheme had been dictated by the need to economise on radar equipment but the Air Ministry considered the need for effective performance to be greater. Headquarters Coastal Command, when recommended to place all installations on a permanent basis, stated that it was appreciated that frequent movement of mobile equipment from one place to another damaged the feeders and upset the correct operation of the installation but denied that in practice moves were frequent. The spare set was seldom used and was held mainly against emergencies. Installation plans through the early part of 1944 consequently proceeded on the basis of one preferred site for each airfield and several subsidiary sites. In October 1944 Headquarters No. 26 Group again stressed the undesirability of the policy because of the danger of beam swing. It was recommended that two preferred sites should be chosen at each airfield and provided with mains power supply, a beacon in a standard hut, standby power supply and remote control facilities, and that the two sites should be complementary to each other. Headquarters No. 26 Group considered that the works services involved would not be excessive as at most airfields the subsidiary sites could easily be supplied with mains power. Headquarters Coastal Command finally agreed to the suggestions, subject to approval being obtained from the Director-General of Works.[1] The Air Ministry therefore requested Headquarters No. 26 Group to review all Coastal Command airfields equipped with B.A.B.S. Mark IC and to submit an estimate of the extra works services involved.[2]

In the meantime progress was made with works services at the airfields chosen for B.A.B.S. installation, although held up to some extent by the shortage of material and labour, and by 15 December 1943 works services had been completed at 21 airfields in Coastal Command.[3]

Monitoring and Servicing

Headquarters No. 26 Group was responsible for testing and calibrating each new B.A.B.S. installation before it was handed over to the user command. Acceptance standards had been compiled for each version from the initial tests carried out on development models. To meet the commitment the Signals Development Unit, which absorbed the former Beam Approach Development Unit, was formed in the spring of 1943 and was based at Hinton-in-the-Hedges.[4] The unit was incorporated in the Signals Flying Unit when the latter was established at Honiley in August 1944, and its responsibilities in regard to B.A.B.S. were taken over by the new unit.

After initial acceptance tests had been completed by No. 26 Group, monitoring was a unit responsibility. Accurate monitoring of the beam was essential

[1] A.M. File CS.18618. [2] A.M. File C.16261/44. [3] A.M. File C.16192/44.

[4] A.M. File CS.18612. The unit used four Anson aircraft, two equipped with A.S.V. and two with A.I.

to ensure perfect alignment, and Headquarters Fighter Command considered after experience had been gained with the experimental A.I. B.A. installation at Ford, that regular monitoring of the beam was a necessity if aircrew were to retain confidence in the system. The monitoring equipment used in Coastal Command consisted of a van containing A.S.V. Mark II, a petrol-electric set, and an aerial system, and was thought to be adequate, but in the autumn of 1943 Headquarters Fighter Command stated that the equipment did not meet requirements because it was unreliable. At Ford a simple monitoring system constructed by the T.R.E. was used. Headquarters Fighter Command considered it to be the more satisfactory method and requested its provision at 40 airfields. The equipment was criticised in December 1943 by the R.A.E. as having too small a range, the maximum being 50 yards. Technical experts felt that monitoring could only be carried out satisfactorily at a distance of 100 yards and recommended the adoption by Fighter Command of a monitoring system similar to that used in Coastal Command. In April 1944 the R.A.E. produced a new method with a range of 170 yards which was accepted by Headquarters A.D.G.B. It was installed at Wittering, where the F.I.U. had moved to from Ford, on 8 May 1944. In June 1944 the F.I.U. reported that it was satisfactory for establishing the position of the beam and provided an approximate indication of power output but it gave no indication of pulse shape or of receiver sensitivity.[1] Development was continued with the aim of evolving a comprehensive monitoring system acceptable to both commands.

In February 1943 an R.A.E. system of remote monitoring had been demonstrated to Fighter and Coastal Commands but, although it indicated whether or not the beam was radiating, it gave no information of beam alignment, and was only partially satisfactory. A similar system which included some means whereby beam alignment could be checked in the airfield control tower was required. In October 1943 an experimental remote control unit made at Ford by the R.A.E. was demonstrated to Headquarters No. 26 Group who considered it to be sufficiently promising to warrant further development. It made use of existing telephone lines from the operations room to the beacon, and provided remote switching of the beacon, two-way telephone facilities, audible monitoring, and a means whereby a separate interrogator could be remotely switched if desired. However, effective remote control was not achieved until B.A.B.S. Mark II had been developed.

The responsibility of Headquarters No. 26 Group for B.A.B.S. servicing was limited to the remedy of faults which were too complicated for units, who were responsible for routine servicing, to deal with. In order that B.A.B.S. might be operated with maximum efficiency, standard servicing schedules, based on those used for S.B.A., were compiled by the R.A.E.[2] Daily inspections were carried out by unit personnel, and the S.F.U., Honiley carried out six-weekly and quarterly ground and air checks. Alignment of the beam was checked two or three times daily with a mobile monitor.[3]

Allocation Overseas

In October 1942 an operational requirement was raised, by both Coastal and Fighter Commands, for a transportable B.A.B.S. which could be erected and set up in working order within six hours of its arrival at a site, for standby use

[1] A.M. File C.16261/44. [2] A.M. File CS.18619. [3] A.M. File C.16261/44.

if the permanent installation should fail.[1] The provision of mobile A.I. B.A. presented a much greater problem than did that of the Coastal Command system because of the large corner reflectors in the aerial array of the former. In February 1943 the R.A.E. reported that the first prototype mobile A.S.V. B.A. equipment was nearing completion. The mounting of Yagi arrays on a signals van had been achieved comparatively easily, but no method had been found for providing an adequate mobile A.I. B.A. aerial system. Attempts were therefore made to mount the beacon and its feeders on a small covered trailer. Headquarters Coastal Command estimated the requirement for mobile B.A.B.S. equipment to be 65; Headquarters Fighter Command required only four at that date but anticipated that overseas commitments would increase the number.[2] When the R.A.E. completed the prototype a development contract was placed with the firm of Centrup. The Coastal Command requirement was cancelled at the end of the year but as development was far advanced by then it was decided to allow the development contract to be completed.[3]

Development, production, and installation of B.A.B.S. Mark I was so slow that very little equipment could be spared for use in overseas commands. However, at the end of 1943, when the Coastal Command requirement for mobile equipment was withdrawn, six mobile B.A.B.S. were allocated from the development contract when an overseas requirement was raised. They were ready by March 1944 and were despatched to No. 338 Wing in North Africa, and to Nos. 323 and 325 Wings in Italy.[4] In June 1944 Headquarters A.C.S.E.A. asked for 33 mobile A.S.V. B.A.B.S. and 32 mains-operated A.I. B.A.B.S. No more mobile A.S.V. B.A. equipments were immediately available and A.I. B.A. had not then been installed in the United Kingdom and could not be allocated overseas until satisfactory Service trials had been held. However, sufficient equipment had been ordered to enable the needs of A.C.S.E.A. to be met eventually. In August 1944 the Air Ministry signalled that ten A.S.V. B.A. installations were likely to be available by late September, but delays in the production of A.I. B.A. meant that allocations were unlikely before December 1944. The commitments in Europe were the more urgent, and in October 1944 three A.I. B.A. installations were despatched to No. 85 Group. One was installed at Amiens/Glisy and another at Lille/Vendeville. As the equipment underwent trials until the beginning of March 1945, only slight operational use had been made of it when it was withdrawn at the end of that month with the transfer to a forward area of the squadrons. Results were never very satisfactory, the chief technical fault being that of beam drift.[5] By the winter of 1945 an installation of B.A.B.S. Mark IC had been made in the Azores.[6]

Development of B.A.B.S. Mark II

Both versions of B.A.B.S. Mark I contained inherent technical faults which, in spite of continuous experimental work and the incorporation of numerous modifications, were never completely eradicated, and performance was never entirely satisfactory. The size of the side-lobes of the aerial radiation pattern, already large, was increased even more if the beacons were not set up carefully on the correct frequency, thus providing false equi-signal paths, some of

[1] A.M. File CS.18618. [2] A.M. File CS.18618. [3] A.M. File C.16192/44.
[4] A.M. File C.16192/44.
[5] A.H.B./IIS/88/2. Radar in 2nd Tactical Air Force.
[6] A.M. File CS.24130.

which were about 40 to 50 degrees off the line of the runway, which dangerously confused aircrews. The equi-signal zone could be swung out of alignment with the centre of the runway very easily because the two transmitter aerials were fed by two separate lengths of high-frequency cable which were apt to change their characteristics as they became affected by weather conditions. This meant that the signals arriving at the two aerials were not equal and the difference accounted for the beam swing. Beam swing was aggravated by the fact that any change of impedance at the aerial input caused the transmitter coupling to change and resulted in frequency-pulling as well as a change in the power delivered to the two feeders.[1] The B.A.B.S. display on the aircraft installation indicator was rather confusing, especially to less experienced aircrews. The method used, comparison of changes in signals amplitude, was undesirable in an aircraft equipment where the tendency was always towards unsteady amplitudes, caused by factors such as propeller modulation, changes in aerial field strength patterns due to changes in aircraft altitude, and ordinary aircraft vibration. The faults of B.A.B.S. Mark I, disclosed in practical operation, provided a basis upon which the improved B.A.B.S. Mark II was developed.

The inauguration of a development programme for an improved version of B.A.B.S. arose in the first place from an expressed requirement for a beam approach system to work with Rebecca. In December 1942 a modified form of B.A.B.S. Mark IF was installed at Tempsford to provide approach facilities for aircraft of the special duty squadrons. As a result Headquarters Army Co-operation Command asked for the provision of a fully mobile B.A.B.S. equipment because its relatively small bulk and small power requirements, compared with those of S.B.A., would make it readily adaptable for use at forward airfields. The installation was required to operate on the frequencies of Rebecca, the only interrogator available in aircraft of the command. In February 1943 the T.R.E. produced an experimental model for trials at Netheravon and on 19 March 1943 it was agreed that the T.R.E. should construct a further 12 sets for use in Army Co-operation Command. In June 1943, however, the plan was abandoned so that the resources of the T.R.E. might be concentrated on research work in connection with a wide-band Eureka B.A.B.S. system being developed for use with Lucero in Bomber Command. It was felt that if a successful fixed B.A.B.S. installation was evolved, mobile and portable versions could easily be developed.[2] In any event, a complete redesign was needed to overcome the inherent defects in B.A.B.S. Mark I, and the fact that Lucero was being installed in all aircraft equipped with centimetric A.S.V. and H2S necessitated the provision of an efficient beam approach system to work with it. In June 1943 trials were conducted at Beaulieu by the T.R.E. to investigate the performance of Lucero Mark I with all types of Coastal Command beacon. It was found that Lucero was unsatisfactory with B.A.B.S. Mark I because its low power output, compared with that of A.S.V. Mark II, resulted in a reduction by approximately two-thirds of the ranges normally obtained.[3] In addition the wide frequency band of the Lucero receiver resulted in signals from both B.A.B.S. and the homing beacon appearing on the indicator simultaneously.[4]

[1] Early beacons were not provided with a power amplifier stage between the oscillator and the aerial.

[2] A.M. File CS.19185.

[3] A.M. File CS.19143.

[4] M.A.P. File SB.18642, Part II.

Development was required, therefore, of a wide-band system covering the frequencies 214 to 234 megacycles per second. Eureka Mark II was to be used as a basis, although it was unsuitable in its existing form. The frequency emitted by the beacon varied with the reactance of the load and while the variation was not sufficiently great to affect the beacon seriously when used for homing, it was not satisfactory in the approach function and might lead to beam instability. In addition, the power output was not independent of pulse width and it was proposed to use a 'wide-narrow' type of display. Necessary modifications included an increase in size, circuit changes, and the inclusion of a power amplifier.[1] A new display, less confusing than that used with B.A.B.S. Mark I, was also required, and to obtain the required coverage, the simple aerial system used with B.A.B.S. Mark I had to be replaced by one with wide-band characteristics.

During 1943 the problem of an approach system for Bomber Command became more pressing. S.B.A. had been adopted before the war but in January 1943 the Inspector-General of the R.A.F. after an investigation had come to the conclusion that the operational use of the system in Bomber Command did not justify the effort expended upon it. In the summer of 1943 a new radar approach system, Ground Controlled Approach, had been introduced into the United Kingdom from the U.S.A. and had proved its worth in operational trials. A committee was therefore formed in September 1943 to investigate the problem of radio aids to flying control, with particular reference to the needs of Bomber Command for an efficient approach aid. The committee considered that G.C.A. was the best alternative to S.B.A. but, as its use was limited by the small number of R/T channels available, it was recommended that existing B.A.B.S. systems should be retained in Coastal and Fighter Commands and that Eureka B.A.B.S. should be developed as a replacement for S.B.A. at Bomber Command airfields where G.C.A. was not available.[2]

On 5 November 1943 a conference was held at the Air Ministry to discuss the recommendations of the committee and to decide future policy for the use of radio aids for flying control in all commands. The relative merits of G.C.A., S.B.A. and B.A.B.S. were considered. Headquarters Bomber Command wanted to replace S.B.A. by a suitable version of B.A.B.S. for the use of aircraft which could be fitted with Lucero. It was therefore decided that G.C.A. would be installed where possible, that most aircraft would make use of B.A.B.S., and that the use of S.B.A. would be gradually discontinued. It was agreed that the provision of a radio glide path was an operational requirement if B.A.B.S. was employed but its development was to be on a low priority.[3] It was hoped that the use of Eureka B.A.B.S. would enable a universal homing system to be developed for all commands. The B.A.B.S. versions previously developed could be used only by aircraft of the command for which they were designed. The rigidity of this system was one of its disadvantages. It was intended that B.A.B.S. for Bomber Command should operate on frequencies of 214 to 234 megacycles per second with vertical polarisation, that for Fighter Command on frequencies of 193 to 196 megacycles per second with vertical polarisation and that for Coastal Command on 176 megacycles per second with horizontal polarisation.[4]

[1] A.M. File CS.19143. [2] A.M. File S.97074. [3] A.M. File S.97074.
[4] M.A.P. File SB.41807, Part I.

In September 1943 Headquarters Bomber Command requested installation of the B.A.B.S. equipment being developed for use with Lucero Mark II at the Bombing Development Unit, Newmarket, for trials to determine whether the new system was sufficiently superior to S.B.A. to justify its introduction in Bomber Command. The T.R.E. was therefore instructed to proceed with the preparation of equipment for Bomber Command trials.[1] By November 1943 development had reached a fairly advanced state. The beacon consisted of a low-power battery-operated receiver/transmitter, a switched cavity resonator aerial system and a short range monitor, the whole being housed in a small vehicle. The cavity resonator in the aerial system required further development because no satisfactory switching mechanism had been devised. A super-regenerative receiver was used but a superheterodyne receiver was also being developed and it was suggested that this should be used for fixed installations where power was available. By December 1943 the first experimental model of the new system was ready for trials at the Telecommunications Flying Unit at Defford, but these were held up until the end of January 1944 by bad weather. During early experimental work difficulty was experienced by the T.R.E. in finding a name for the new equipment. It was at first decided to refer to it as radar B.A., and later in its development the beam approach equipment for Bomber Command was known as Eureka B.A.B.S.[2] On 8 May 1944 the name Lucero B.A. was adopted, the homing beacons being referred to as Eureka beacons. On 5 June 1944 the name was again changed and thereafter permanently remained as B.A.B.S. Mark II.[3]

The improved aerial system of B.A.B.S. Mark II was a distinctive feature of the new equipment. It consisted of a metal cavity with two radiating slots mounted in a corner reflector, the slots being energised from a common source and switched alternately by mechanical shorts across them. It operated both as a receiver and transmitter system for vertically polarised radiation on spot frequencies between 214 and 234 megacycles per second; the receiving and transmitting frequencies were, in general, different. The radiation pattern took the form of one or the other of two mutually symmetrical off-centre beams which could be switched alternately at 10 cycles per second. The beam was switched simultaneously to code the beams so that short pulses of radiation of 5 micro-seconds duration (dots) were transmitted in one beam and long pulses of 12 micro-seconds duration (dashes) in the other. Bearings of range from the runway were indicated in aircraft installations by amplitude ratios of signals received from the two beams. The fact that the new system used a single feed cable and a single unipole or probe meant that one of the most serious faults of B.A.B.S. Mark I was eradicated; it was free from inequalities of beams arising out of variations in matching or attenuation in separate feed cables. Beam symmetry in B.A.B.S. Mark II was completely dependent on physical symmetry of the aerial system. The probe which energised the aerial was constructed of 3⅛-inch brass tubing projecting through a central hole in the top of the aerial box. Different probe lengths had to be provided for different frequencies in the band. The aerial was switched by shorting the centre of the slot, which was not required to radiate. Switching was effected by a relay at each slot and the relays were controlled by a master relay which ensured that one slot was closed before the other opened. Coding of the transmitted pulses was done by means of two high-speed relays in the beacon transmitter which governed the pulse

[1] A.M. File C.30496/46. [2] M.A.P. File SB.41807. [3] A.M. File S.97074.

B.A.B.S. Mark II Aerial System

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length. When one relay was operated narrow pulses were transmitted and when the other was operated wide pulses were transmitted. A high-speed relay could only operate when the appropriate slot was open and the other closed, so that when both slots were closed no transmission took place.[1] The new method of display involved no change in the aircraft apparatus but the ground aerials were switched symmetrically and arranged so that the broad pulse from the beacon was switched in during the radiation period of the left-hand beam to give dash sectors and a narrow pulse during the radiation period of the right-hand beam giving dot sectors. Thus the display on the aircraft indicator was such that narrow and broad echoes were viewed simultaneously, one within the other. On the equi-signal path the amplitudes were identical. When the aircraft was in the dot sectors the narrow blip protruded out of the broad blip and the ratio of amplitudes denoted the various dot sectors. When the aircraft was in the dash sectors the broad blip predominated.

Flight Trials

Flight trials of an experimental model of B.A.B.S. Mark II were held at the Telecommunications Flying Unit, Defford, from 27 January to 1 March 1944, with an Oxford aircraft equipped with Rebecca Mark II. During 16 flights 42 approaches were made, 32 of them open and 10 hooded. The large number of open approaches were made so that the accuracy and reliability of the system could be tested and a check made of the standard of performance of the equipment in the hands of inexperienced radar operators. The trials were carried out mainly in very bad weather. The ground equipment was switched on for 43 hours altogether. The performance obtained was encouraging. Strong signals were received at 1,000 feet out to ranges of at least 10 miles. At first a very severe modulation of pulses, approximately 50 per cent of the signals, was apparent. It was ascertained that the fault was propeller modulation and an interim remedy was sought by the installation under the aircraft fuselage of an aerial in such a position that the propellers did not affect it.[2] At 5,000 feet signals from the beacon were received at 40 miles when the aircraft was facing it. Throughout the trials the beam remained aligned with the runway and was of a suitable width—approximately one degree. An attempt to use a small Eureka beacon at the touch-down end of the runway as a boundary marker failed because the Eureka signal disappeared into the direct pulse at approximately one mile. Presentation in the aircraft was more satisfactory than the earlier B.A.B.S. display. The time of approach was reduced because it was possible to identify the sector by the width of the pulse. The clearly marked linear scale gave accurate ranges. The system of transmitting on one frequency and receiving on another avoided confusion with ground returns. The navigators, most of whom were not used to the B.A.B.S. approach method, gave the pilots information of beam sector and range, and were able to make good approaches at the first attempt in spite of lack of experience. The mobility of the equipment was a further point in its

[1] M.A.P. File SB.41807. The original conception of B.A.B.S. Mark II, including the particular type of slot aerial and the broad and narrow pulse display, was that of Mr. K. A. Wood of the T.R.E.

[2] M.A.P. File SB.41807. Propeller modulation was a variation of signal due to variations in the phase, amplitude, and direction of radiation reflected from the rotating propeller blades. When it was present both the D.F. ratio and the amplitude of the signal were liable to fluctuate in an erratic manner and confuse the C.R.T. display.

favour since it took twenty minutes only to move the beacon from one end to the other of a 2,000-yard runway and to realign the beam.[1]

In February 1944 a second experimental installation built by the T.R.E. was despatched to the Bombing Development Unit for comparative trials with S.B.A. The general opinion after the trials was that the system was preferable to S.B.A. in many ways. The aircraft installation display was interpreted by the navigator so that the pilot did not have to concentrate so hard as with S.B.A. and could focus his attention on flying accurately. Far less training and practice was required than with S.B.A. because three or four hours in the air was enough to enable most operators to achieve a high standard of reliability. It was thought that control from the ground could be more easily effected with B.A.B.S. than with S.B.A. because it was not necessary for an aircraft to be in the beam before a pilot could ascertain his exact position. The information made available on the indicators of Lucero and Rebecca was more comprehensive than that supplied by S.B.A. B.A.B.S., within a given area, supplied an instant and accurate fix in terms of range and bearing so that a course could be set for any point within the beacon range. S.B.A. supplied a single position line, and specific fixes only at the outer and inner markers. Also, the degree of accuracy of a B.A.B.S. fix was higher than that obtained with S.B.A. The circle of error at the S.B.A. inner marker was about 80 yards in diameter while at an equivalent position when B.A.B.S. was being used the diameter of the circle of error was about 40 yards. During the trials the B.A.B.S. ground installation was operated for 103 hours without a fault and was serviced by R.A.F. radar mechanics with only occasional supervision by T.R.E. personnel.[2]

One of the problems encountered during the Defford trials was distortion of the beam caused by reflections from hangars or similar structures on the airfield. This distortion was not so pronounced in the new system as in B.A.B.S. Mark I because no large side lobes were radiated but there were some reflections on the approach line from the sides of the main forward lobes. At Defford no distortion occurred in the normal approach run but only on the runways themselves. The useful opportunity offered of carrying out tests to eliminate distortion on other airfields was accepted. In June 1944 the T.R.E. obtained authority to experiment with a sloping screen of fine wire mesh suspended from the roof of a hangar at Defford down to the ground, facing the landing area at an angle of 45 degrees with the horizontal, in order that incident radiation would be reflected upwards where it could not interfere with any part of the beam normally used by aircraft.[3]

Difficulties were experienced in May and June 1944 over the discrepancies in range measurements obtained with Lucero. Headquarters Bomber Command stated that circuit delays in the ground and aircraft equipment varied through a wide range and in consequence the equipment was operationally unacceptable. The method of calibration was unsatisfactory. A measurement, to within plus or minus 200 feet, of the range of aircraft from the downwind end of the runway was required. The T.R.E. investigated the problem and devised a new setting-up procedure and new test gear, but it was found impossible to guarantee a better accuracy than plus or minus 100 yards, which, however, was accepted by Headquarters Bomber Command.[4]

[1] A.M. File S.97074. [2] A.M. File S.97074. [3] M.A.P. File SB.41807.
[4] A.M. File CS.22955.

Production

Although the B.D.U. trials were successful, it was not until 22 April 1944 that Headquarters Bomber Command stated a firm requirement for the installation of B.A.B.S. Mark II, to work in conjunction with Lucero, at all operational and O.T.U. airfields. Provision was planned on the basis of one mobile set per airfield at first, to be followed by fixed installations in addition to one mobile equipment for use as a standby in the event of failure of the main beacon.[1] A requirement for a glide path indicator for use with B.A.B.S. because of the lack of height information was also stated, but its development at the T.R.E. was given low priority.

Both the Ministry of Aircraft Production and the T.R.E. were concerned in the choice of a radio firm for the development and production of B.A.B.S. Mark II and B.A.B.S. Mark IIM, the mobile version. After the capacity of several had been investigated the firm of Pye of Cambridge was considered the most suitable, and was given a development contract for ground equipment in January 1944.[2] Pye estimated that development models could be delivered by May 1944 and a start made on quantity production by August. The development contract was originally for four prototypes but in May 1944 this was increased to ten with the highest priority.[3] Of these one was to operate on the A.E.A.F. frequency band. A requirement had been raised by Headquarters Allied Expeditionary Air Forces for a mobile B.A.B.S. system, to work in conjunction with A.I. Mark VIII and Lucero, for the use of night-fighter aircraft of No. 85 Group. Specifications included a compact aerial system, a simple and reliable siting device for rapid and accurate alignment, and a minimum range of 15 miles. The T.R.E. considered that B.A.B.S. Mark IIM could be modified effectively to operate on 193 megacycles per second. The placing of the production contract was held up because of delay in obtaining financial sanction.[4] This was finally obtained and in July 1944 the Ministry of Aircraft Production placed a production contract with the same firm for 130 fixed and 460 mobile installations and spares sufficient for 12 months' maintenance.[5] The first development model was ready in June 1944 but it was considered to be technically faulty by the T.R.E. and work was begun on a new model which was not ready for type approval until the end of August. The Ministry of Aircraft Production considered that the delay of six weeks was justified because it was essential for the successful introduction of B.A.B.S. Mark II into the Service that the equipment was entirely free from technical faults.[6] Meanwhile Headquarters Bomber Command had become increasingly interested in the B.A.B.S. programme because of the slow rate of production

[1] A.M. File C.30496/46. Allocation was planned as :—

Bomber Command operational airfields		..	95
Bomber Command diversion airfields	..	..	170
Bomber Command training units	..	..	23
Allied Expeditionary Air Forces	..	..	20
United States Army Air Force	..	..	20
India (for bomber airfields)	..	..	6
Reserve for overseas requirements	..	..	50
		Total ..	384

(A.M. File S.97074.)

[2] M.A.P. File SB.41807 and A.M. File C.30496/46.
[3] A.M. File S.97074.
[4] M.A.P. File SB.41807.
[5] M.A.P. File SB.41807.
[6] M.A.P. File S.97074.

of G.C.A. in the U.S.A. and because stocks of S.B.A., the contract for which had not been renewed in the spring of 1944, were diminishing. On 4 May 1944 the Bomber Command groups agreed on a plan to ration out existing stocks of S.B.A. rather than renew the contract because that would delay the supply of modern equipment. At the same time the inauguration of an immediate crash programme, to provide Lucero for two squadrons equipped with H2S, and B.A.B.S. installations at two stations, so that squadrons might obtain operational experience of the new approach system, was recommended.[1] The urgent need for an efficient approach aid at Bomber Command airfields was realised at the Air Ministry and Ministry of Aircraft Production, and arrangements were made to meet the request for a crash programme to enable adequate knowledge of the system to be obtained before a full-scale installation programme was begun. On 5 June 1944 authority was given for the necessary works services to be undertaken at Wickenby and Driffield.[2]

At progress meetings held periodically arrangements were completed for both the crash and the main B.A.B.S. programmes including such matters as technical development, the rate of production of both ground and aircraft equipment, works services, and installation plans, but production on development and main contracts proceeded very slowly. Initially delays had occurred because priority was not high, but even after the Air Staff had increased priority because of the urgency of the need for Bomber Command to have an efficient approach system in operation by the following winter the rate of manufacture was still slow because of congestion in the Pye workshops, where Oboe and H2S were also being made.[3] On 27 September 1944 Headquarters Bomber Command complained about the delay on the grounds that earlier in the year it had been agreed to remove S.B.A. from some groups on the understanding that B.A.B.S. would be available before the approaching winter. As a result they were faced with the prospect of many aircraft being without an approach aid during winter bombing operations. Unless aircraft could fly in all weathers the highly developed systems of blind bombing would never be fully employed. The Air Ministry considered that Headquarters Bomber Command was partially responsible for the situation as the urgency of the need for B.A.B.S. had not been stressed until late in the summer of 1944 and even then it had not been made clear whether B.A.B.S. was required at the expense of other radar systems such as H2S, Gee, Gee-H, and A.G.L.T. In October the installations at Driffield and Wickenby were almost completed and installation at other airfields was not anticipated before the end of the year. The Air Ministry refused to sacrifice technical efficiency in favour of speedy production. Headquarters Bomber Command was assured that every effort was being made to implement the undertaking to provide B.A.B.S. facilities for the bombing operations of the winter 1944/45.[4] It was for this reason that the T.R.E. was asked in the autumn of 1944 to manufacture six emergency equipments in order to ensure that there was a skeleton B.A.B.S. organisation in Bomber Command before delivery from the main programme

[1] A.M. File S.97074.

[2] Wickenby was to have the first B.A.B.S. mobile ground installation and No. 12 Squadron (Lancasters) at Wickenby was to be the first squadron to be fitted with Lucero. The first B.A.B.S. fixed ground equipment was also to be installed at Wickenby. Driffield was to have the second and third mobile B.A.B.S. installations. No. 466 Squadron (Halifax) was to be the second squadron to be fitted with Lucero. (A.M. File S.97074).

[3] A.M. Files C.30496/46 and S.97074.

[4] A.M. File S.97074.

was begun. They were similar to the development models produced for the Wickenby and Driffield trials, but contained only one beacon per installation, so that there was no standby set, whereas the Pye models had two beacons.[1] The T.R.E. sets were not as fully engineered as those built by the radio manufacturers and the absence of a standby set meant that the failure of a component part put the whole system out of action. The T.R.E. therefore suggested that four of the six sets might be used to provide spares for the four installations at Wickenby and Driffield and the remaining two to equip another Bomber Command airfield.[2] The Air Ministry ruled that the first four sets might be used for ensuring the provision of 100 per cent spares at Wickenby and Driffield but Headquarters Bomber Command preferred to await delivery from main production for installation at other airfields, rather than use the T.R.E. sets.

Service Trials

It had been originally intended that Pye production models should be used for the Wickenby and Driffield trials but the slow rate of production and the delay in obtaining type approval necessitated the use of equipment from the development contract. Trials at Wickenby began with two mobile installations and 19 aircraft of Nos. 12 and 626 Squadrons fitted with Lucero. Some faults were experienced with the aircraft and ground equipments but these were attributed to the fact that the apparatus was new and not to any serious fundamental defect. At the very outset of the Wickenby trials an effort was made to overcome one of the difficulties of the operation of beam approach equipment, that of ensuring an adequate standard of training. Therefore, the training in B.A.B.S. was designed to incorporate as much as possible of the normal landing procedure. Pilots, navigators, and flight engineers were given two hours' ground training. This was followed by air training which averaged about one hour dual and 1½ hours solo. After that approaches using B.A.B.S. were practised on all non-operational flights. Three special exercises were held on 11, 12 and 13 December 1944 and on each of these ten aircraft used B.A.B.S. for landings. On the first day the aircraft were landed in 40 minutes in visibility of 1,500 yards and when the cloud-base was 2,500 feet. On the second they were landed in 54 minutes in bad visibility of 800 yards decreasing to 400 yards. One aircraft whose Lucero equipment was unserviceable was led in by another which itself made an overshoot. During these trials the approach run was reduced to 4 miles, which was found quite satisfactory. On 24 April 1945 a special B.A.B.S. exercise was held at Wickenby in which 15 aircraft took part. Pilots were briefed to arrive at a point 94 miles from the airfield, known as the gate, in four waves at three-minute intervals, and to report arrival by R/T, at a height of 15,000 feet, to the control tower, from where approach and landing instructions were issued. All 15 aircraft were landed in 33 minutes.[3]

In December 1944 Headquarters No. 1 Group forwarded recommendations to Headquarters Bomber Command. It was felt that the system was simple enough for an average crew to learn quickly, and that up to 20 aircraft per airfield could be landed at intervals of three minutes in visibility of 800 yards using an oval circuit approach. A serious disadvantage was the reliance upon the altimeter for recording height information; and a glide path indicator

[1] A.M. File C.30486/46.
[2] A.M. File CS.22955.
[3] M.A.P. File SB.41807, Part II.

was a definite requirement. It was recommended that the interrogator/indicator should be entirely independent of H2S so that the serviceability of the former was not dependent on that of the latter. This recommendation was supported by Headquarters No. 4 Group when reports of trials being held at the same time at Driffield were submitted. At one time difficulty was experienced in aligning the beam of the fixed installation at Driffield but it was found to be due to the proximity of bulldozers and other metal equipment, and when these were removed no further trouble was experienced.[1] Another complaint was made about the misalignment of the mobile beacon which resulted in pilots making a 'dog-leg' involving a 10-degree alteration of course. It was feared that the danger of this manoeuvre would cause aircrew to lose confidence in B.A.B.S. and thus prejudice its successful introduction into the R.A.F. T.R.E. investigation of the problem revealed that the misalignment was caused by the moving of a monitor post in front of one of the beacons and when this was corrected the beacon operated satisfactorily. The trials provided an opportunity to compare the performances of fixed and mobile beacons. It was reported in January 1945 that both fixed and mobile beacons gave the same results from the air, but whereas the fixed beacon seldom wandered once it was aligned, the mobile beacon was difficult to set up accurately and could never be guaranteed. This meant that the monitoring of the fixed beam could be carried out by occasional checks during air tests and slight corrections made to align the beam accurately along the runway, but with the mobile type it was necessary to rely on correct visual alignment. In May 1945 the T.R.E. conducted tests with the B.A.B.S. installation at Driffield and reported that when the beam was aligned by means of the monitor system it was accurate, that the beam width was sufficiently narrow to ensure an approach to the centre of the runway within plus or minus 25 yards, and that no false beams occurred in the sector 90 degrees to either side of the beacon line-of-shoot.[2]

Installation at Home and Overseas

At the end of October 1944 the Air Ministry estimated that December 1944 would see the beginning of the main B.A.B.S. programme for Bomber Command. It was hoped that 14 airfields would be fitted by the end of December and 70 to 80 by the end of March 1945.[3] Unfortunately the estimates proved to be unduly optimistic and it was not until the end of February 1945 that the first production models of B.A.B.S. Mark II arrived at the T.R.E. from the contractors. By April 1945 11 sets had been delivered, and were first sent to No. 26 Group for testing and then to the chosen airfield for installation, the requirements of Bomber Command being given priority. By the end of the war in Europe 28 equipments had been produced and by the end of July 1945 44 had been delivered to No. 26 Group. Of this number 21 had been despatched to Chigwell for the Tiger Force commitment, including six for staging posts. By then installations had been completed at 11 airfields in the United Kingdom.[4]

[1] A.M. File CS.22955. [2] A.M. File CS.22955. [3] A.M. File S.97074.

[4] They were :—

(a) Defford, Newmarket, Netheravon, Bottisham, Shepherd's Grove and Mildenhall for development and trial purposes;

(b) Wickenby, Driffield, Ludford Magna, Coningsby and Metheringham for Bomber Command operational requirements.

Of these 12 runways had Class A beams, that is, beams passed by Headquarters No. 26 Group as perfect for CRT presentation purposes, and 14 runways had Class B beams, that is, beams in which the 'on beam' path was perfect but which contained slight discrepancies of ratios in the outsectors.[1]

With the end of the war in Europe and the cessation of bombing operations against Germany Bomber Command requirements dropped sharply and those of Tiger Force took first place. It was decided that B.A.B.S. Mark II was to be provided for this force but, as it was not likely that all would be equipped with H2S, Rebecca Mark II was also required. At a meeting on 8 June 1945 first priority was given to the provision of training facilities within Technical Training Command and Bomber Command for Tiger Force. Production was still very slow and careful assessment of claims to equipment was essential.[2] In March 1945 Headquarters Transport Command had asked for an allocation of B.A.B.S. Mark II because no SCS. 51 equipments had been received. Six installations were required along the U.K./Karachi route for the use of reinforcement aircraft, and installation was also required at 14 terminal airfields in the United Kingdom. In June 1945 the requirement was increased to 54 equipments and Headquarters Transport Command predicted that the demand would eventually be for 60. In August 1945 the Air Ministry ruled that any B.A.B.S. equipment not required for Tiger Force could be used on the U.K./Karachi route.

With the cessation of hostilities the priority for B.A.B.S. Mark II was again altered, the primary task of the R.A.F. having become the transport of troops; in October 1945 the trooping commitment was given overriding priority.[3] With the cessation of Lease-Lend, Transport Command was faced with the danger of the failure of supplies of SCS.51, and the Chief of the Air Staff ruled that work was to be accelerated on any buildings or ground installations necessary for Transport Command use and was to have priority over Bomber Command projects, other than at airfields used for Bomber Command trooping.[4] By the end of October 1945, 118 equipments had been received from the manufacturers and the task of siting and installation was going ahead both at home and overseas. Prestwick, Melbourne, Holmesley South, and Blackbushe had each been provided with one mobile set.[5]

In September 1945 Pye produced the first B.A.B.S. Mark IIM modified to operate on 193 megacycles per second. This was called B.A.B.S. Mark IIFM and was sent to the T.R.E. for type approval in November 1945. It did not operate satisfactorily but the T.R.E. attributed this not to its adaptation to the Fighter Command frequencies but to faults in manufacture. Once these were cleared the T.R.E. agreed to give type approval, and considered that the necessary modifications to produce B.A.B.S. Mark IIFM from Mark IIM could be incorporated by Service personnel. Fighter Command sent four radar mechanics to the T.R.E. for training and by January 1946 they had modified one model there. It was sent to West Raynham for trials. In the spring of 1945 the Air Ministry stated a requirement for an air transportable model of B.A.B.S. Mark IIM to be known as B.A.B.S. Mark IIA. A development contract was placed with the firm of Pye in June 1945 but work did not

[1] T.R.E. Memorandum 43/M.14/KAW. B.A.B.S. Mark II—Summary of Performance.

[2] A.M. File C.30496/46, Part II.

[3] A.M. File C.30496/46, Part II.

[4] A.M. File S.103233.

[5] A.M. File S.103233.

start for some months because the original documents were lost in transit. By the winter of 1945 development work had started on this project.[1]

The rate of production of B.A.B.S. Mark II was so slow that, apart from initial provisioning for Tiger Force and trooping commitments, no equipments were available for installation overseas during the war. One requirement that could not be met was that of the Tactical Air Force, who requested the installation of 10 mobile equipments in north-west Europe at airfields used by communications squadrons. It was considered that B.A.B.S. Mark IIM would be most suitable for installation along the U.K./Karachi route, and the T.R.E. modified standard equipment for use in tropical climates.[2] A T.R.E. representative visited the Transport Command staging posts in July 1945 to advise on the problems of siting and general installation. By the end of September 1945 works services had begun at six airfields, and in the following month arrangements were made for the installation of mobile B.A.B.S. at 10 Transport Command staging posts in the Middle East.[3] In November 1945 the Air Ministry informed Headquarters B.A.F.O. that B.A.B.S. Mark II was to be fitted at six staging posts in Europe.[4]

Headquarters No. 26 Group was made responsible for the siting, installation, calibration, and servicing beyond unit capacity, of B.A.B.S. Mark II at United Kingdom airfields. The command concerned selected an airfield, subject to Air Ministry approval, and specialist siting officers from No. 26 Group surveyed it, chose sites, and forwarded siting plans and works requirement schedules to the Air Ministry. Wherever possible the existing S.B.A. main beacon and inner marker plinths were converted for use with B.A.B.S. Mark II as was the existing mains power supply to sites.[5] A number of aircraft were provided within No. 26 Group specifically for the purpose of undertaking flight trials during installation and for subsequently making periodic checks on the calibration of the ground equipment. Headquarters No. 26 Group found difficulty in keeping fitting parties fully manned in the autumn of 1945 because of full-scale demobilisation, and this slowed down the introduction of B.A.B.S.

At the end of 1944 Headquarters Bomber Command expressed dissatisfaction with the existing policy that S.B.A. was to be removed from airfields before B.A.B.S. was installed, because during the period of B.A.B.S. installation no approach facilities were available. A list was submitted to the Air Ministry of 46 airfields at which it was considered desirable to retain S.B.A. until all operational bomber aircraft had been fitted with the requisite B.A.B.S. equipment and adequate ground installations had been made available. The Air Ministry agreed that this should be done at stations where no increase in works services was involved, but where simultaneous siting was impossible S.B.A. would have to be removed.

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[1] M.A.P. File SB.41807, Part II.

[2] A.M. File S.97074. In July 1945 instructions were issued for spraying B.A.B.S. Mark IIM as a temporary method of tropicalisation until suitable arrangements could be made on production lines. (A.M. File C.30582/46).

[3] Elmas, Luqa, Castel Benito, Shaibah, Bahrein, El Adem, Almaza, Lydda, Habbaniya, Catania.

[4] Melsbroek, Evere, Copenhagen, Oslo, Fuhlsbuttel, Gatow.

[5] A.M. File S.103233.

Technical officers of the T.R.E. who had been concerned with the development work on B.A.B.S. were insistent that adequate measures should be taken to ensure its successful introduction. They feared that if care were not taken to achieve perfect operational efficiency the R.A.F. would lose confidence in the aid and thus be prejudiced against it from the start. Consequently in May 1945 the T.R.E. recommended to the Air Ministry that command parties should be organised to supervise the introduction of B.A.B.S. Mark II and to ensure that it was maintained at the very highest standard. Senior officers should be suitably briefed on the details of the system and its repercussions on the general flying organisation of the Service. Servicing efficiency was important and those responsible should be adequately trained; the emergency servicing party provided by No. 26 Group should be adequately established, reliable and efficient. Adequate control was essential and to this end it was recommended that B.A.B.S. should be absorbed in the local flying control procedure for fair weather landings as frequently as possible. However, in order that confidence in the system was not impaired it was also recommended that B.A.B.S. should not be used if there was any doubt about the performance of an installation. The T.R.E. feared that, if the necessary precautions were not taken, B.A.B.S. Mark II would be no more efficient than S.B.A. had been.[1] The Air Ministry agreed with the T.R.E., established command servicing parties, and when B.A.B.S. was installed overseas, issued instructions based on the T.R.E. recommendations. In October 1945, when plans were made for the installation of B.A.B.S. in the Middle East, a nucleus installation and maintenance servicing party of one R.A.F. officer and 10 airmen was trained in the United Kingdom by No. 26 Group and posted to the Middle East to work under the supervision of a T.R.E. officer. Headquarters Middle East was recommended to build a specialist party from this nucleus to check periodically the efficiency with which the equipment was being serviced at units. Until radar personnel trained on B.A.B.S. equipment were posted from the United Kingdom, station personnel were to be trained by the installation party, which was to be afforded every facility for that purpose.[2] Similar instructions were given to Headquarters B.A.F.O. in November 1945, when it was also decided that a standard aircrew B.A.B.S. drill should be introduced for use at home and overseas. Headquarters No. 26 Group was instructed to prepare a syllabus which was to be incorporated in the Link Trainer Instructors' course. In order to ensure constant practice in the use of the system it was agreed that the drill should be introduced into routine squadron navigation training as soon as each squadron was equipped to use B.A.B.S. The importance of maintaining the equipment at the highest pitch of efficiency was stressed and it was agreed that technical advisers should be included in servicing parties. Instructions were issued that B.A.B.S. installations were to be kept permanently switched on at the end of the runway in use so there was no delay when they were required.[3]

The problem of training mechanics for B.A.B.S. Mark II was discussed at a meeting held at the T.R.E. on 19 July 1944. At that date the problem was two-fold; there was, first, the immediate problem of providing the necessary training for squadrons at Wickenby and Driffield to ensure that the Service trials were not hampered by inefficient servicing, and, secondly, the need for

[1] A.M. File S.97074. [2] A.M. File S.103233. [3] A.M. File C.30582/46.

more comprehensive training courses in readiness for the introduction of B.A.B.S. on a major scale. To meet the first need two radar mechanics from Driffield and two from Wickenby were sent to the T.R.E. for ten days' training. After that the T.R.E. provided two courses, each of four weeks' duration, one in July 1944 and one in the following month. These consisted of a three weeks' conversion course which dealt mainly with the particular radar circuits involved in the radar beam approach technique and a further week on the special problems encountered in B.A.B.S. Mark II. By October 1944, 24 radar mechanics from Bomber Command had been trained at the T.R.E. Thereafter the responsibility was transferred to Technical Training Command and it was agreed that training should commence at Yatesbury in the middle of January 1945. The Air Ministry arranged for B.A.B.S. equipment to be allocated for the purpose but it was not until February 1945 that it was made available and then it was one of the models built by the T.R.E.[1] At the end of October 1945 the Air Ministry confirmed that arrangements had been made for a total of 50 radar mechanics to be trained at Yatesbury before undergoing further training at the S.F.U. Honiley. The first twelve were already there, and twelve or thirteen mechanics were to pass through the radio school every fortnight.

The provision of a remote control and monitoring system was one of the hardest problems to solve. It was required so that beacon installations might be left unattended during operational use. The site of the beacon at the end of the runway was dangerous in the event of an overshoot, and in December 1944 it was reported from Driffield that, owing to overshoots, there had been several occasions on which the beacons had been almost destroyed and the attendant mechanics had had very narrow escapes.[2] Because of the danger the installations at Wickenby and Driffield were left unattended during the period of landing. Headquarters Bomber Command considered this to be very unsatisfactory because the failure of the equipment or the radiation of incorrect information was liable to cause a crash. Consequently it was ruled that installations were to be manned by a mechanic throughout the period of use and any risks run were held to be normal risks of war.

Meanwhile efforts were being made to provide remote control and monitoring facilities. As a result of consultations with Headquarters Bomber Command the Air Ministry raised a requirement in November 1944 for development to be undertaken at the T.R.E. on the highest priority. The requirement was fourfold; remote switching, remote monitoring of the beam, an alarm device, and remote control of the beam.[3] In January 1945 the Air Ministry sanctioned, as an interim measure, a method proposed by the T.R.E. which could be applied to all fixed and mobile B.A.B.S. Mark II installations operated from sites where AC mains and a minimum of four pairs of telephone cables were available.[4] One extra unit was installed with the existing equipment. It included the circuits necessary to display information on any standard indicator of the beam transmission in the control tower. The display allowed a continuous check to be made of alignment of the beam along the runway, of correct radiation of the pulses, and of the aerial switches.

[1] M.A.P. File SB.41807, Part II.
[2] A.M. File C.30582/46.
[3] A.M. File CS.22955.
[4] A.M. File S.97074.

CHAPTER 18

GROUND CONTROLLED APPROACH AND SCS. 51

Early in 1943 it was becoming increasingly obvious that, with the intensification of the bombing offensive, an urgent requirement existed for a system which would enable large numbers of aircraft to be landed speedily and safely in poor visibility. At that time the R.A.F. was using the Standard Beam Approach system. In January 1943 an investigation made by the Inspector-General of the R.A.F. of the use of S.B.A. at operational units revealed that Bomber Command was heavily committed to the system in that 126 airfields had been equipped with the ground equipment and 30,000 aircraft installations had been manufactured by the end of 1942. It was considered that operational results were not justifying the outlay mainly because pilots of operational units were not obtaining adequate practice in beam flying and therefore lacked the confidence which was essential, and because Bomber Command employed a policy of compulsory diversions and so denied pilots the opportunity of using S.B.A. operationally. However, the system was the only one available on a large scale in the United Kingdom.

Description of G.C.A. System

Meanwhile a mobile radar method of blind approach, known as the 'Talk-down' or Ground Controlled Approach system, had been developed at the Radiation Laboratory, Massachusetts Institute of Technology, to the specifications of Dr. L. W. Alvarez. It consisted of two separate radar systems with a common high-voltage power supply. The first was designed for the control of aircraft in the airfield circuit and the second for guiding aircraft down an approach path to the runway. The control system operated on a wavelength of 10 centimetres with peak power of 80 kilowatts and was capable of 'seeing' aircraft at ranges of 15 to 20 miles within angles of elevation of 2 to 10 degrees. Signals were presented on two plan position indicators in parallel with switchable range scales of 7, 15, and 30 miles. The two P.P.I. operators were known as the traffic controller and the despatcher. The approach system operated on a wavelength of 3 centimetres with a peak power of 8 kilowatts. Two dipole aerial arrays giving a narrow fan beam were used; a horizontal array gave a beam approximately 0·8 degrees wide in azimuth and 1·5 degrees wide in elevation, mechanically scanned in azimuth through 14 degrees, and a vertical dipole array gave a beam approximately 0·45 degrees wide in elevation and 3 degrees wide in azimuth, scanned in azimuth through 10 degrees. The driving mechanism was synchronised and the supply of power to the two arrays was controlled by a mechanical chopper geared to the driving motor. Power was alternately switched from the horizontal to the vertical arrays. Since the beam was so narrow, simple servo mechanisms were needed to maintain both arrays on the target. The two systems could be trained around in azimuth through 20 degrees at the azimuth operator's will; the elevation of the azimuth array was maintained at its correct position by the elevation operator. The signals from each appeared on separate B-scope indicators, plotting in rectangular co-ordinates angle versus range.[1] The operator for each cathode ray tube controlled, by means of a hand wheel, the position of a short-line electronic angle marker on his scope. He followed the aircraft signal in his respective co-ordinate by maintaining the angle marker on the centre of the aircraft signal. A third operator, the range man, seated between the other two, followed the aircraft in range with another electronic marker. In doing this, he controlled a cam system, known as the director, which placed the angle marker on the tubes at the desired position of the aircraft in the approach path. In the director there were two cams; the shape of one represented the relationship between the azimuth angle and the range for a given desired approach path and that of the other showed the elevation versus range relationship. Cam followers fed electrically so as to place the electronic angle markers on the tube at the desired angular position corresponding to the aircraft range. When the angle operator moved his marker on to the aircraft signal he automatically cranked out the angular deviation of the aircraft from its desired position. This angular error was multiplied electrically by range and the results appeared on the controller's meter as a voltage proportional to the linear error of the aircraft in that co-ordinate. The controller had three meters, mounted in a panel, in front of him, two giving linear errors of the aircraft in elevation and azimuth, the third being the range meter. From the information thus presented, the controller was able to guide the aircraft down the approach path towards the runway; he also gave the pilot information as to his distance from the airfield boundary. Communication with the aircraft was by means of radio telephony.[2]

The equipment was contained in two vehicles, sited within 50 yards of each other, which were positioned about 50 yards to the port side of the runway in use and about one third of the distance along it from the upwind end. The first contained the radar transmitting and receiving equipment, and the dipole aerial array mounted on the roof, in addition to the diesel-electric power supply. The second, the control room, housed the indicators, the controller's error system, and six radio communication sets.[3]

The first stage of the procedure in assisting an aircraft to approach was that of sorting out and identifying the aircraft nearing the airfield. This was the task of the traffic controller, who gave the pilot flying instructions on one of the R/T channels until his turn came for landing. This operator then handed the aircraft over to the despatcher, who guided the pilot, over a second R/T channel, to a position where the aircraft could be seen on the approach radar system and from which the final approach was to be made.[4] This point was usually about ten miles from the runway and the normal height of the aircraft was 2,000 feet.[5] Instructions on the course to be flown and cockpit drill were given. When the aircraft reached the point at which the final approach was to start a reflected signal was shown on the two 'precision' cathode ray tubes. The operator of each of these followed the path being flown by keeping a spot of light on the signal. The movements of the controls which kept the two spots of light on the

[1] B-scope was a radar display showing position of target in bearing, horizontally, and in range, vertically.

[2] A.M. File S.87187. [3] A.M. File S.95191. [4] A.M. File S.87187.

[5] A.M. File S.89814.

elevation and azimuth signals showed by how much the pilot deviated in azimuth and elevation from the correct approach path. These errors appeared on the controller's meters and he gave the pilot instructions on a third R/T channel, correcting his position in azimuth and elevation so that he flew in on the correct path. At the same time the pilot was told when to increase the angle of flaps and when to extend them fully. He was informed of his distance from the runway at various stages of the approach, and finally at a prearranged distance from the runway he was given the distance and instructed to take over and land the aircraft by visual means.[1]

In addition to the approach instructions given by R/T, an aural signal was given to assist pilots. This was automatically generated from the azimuth error voltage and could be used by pilots who were trained in flying on the beam approach method. This signal gave an aural indication of the position of the aircraft in relation to the azimuth track. It was superimposed on the R/T channel and was regulated so as not to interfere with speech. If the aircraft was to the left of the track the pilot heard a succession of dots which increased in pitch as deviation from the track was reduced. If the pilot was flying to the right of the track there was a continuous note which rose in pitch as the distance from the track increased. As the aircraft was flown along the correct approach path the signal died out and a 'pip' sounded every three seconds to assure the pilot that his R/T was still serviceable.[2]

Service Trials of G.C.A. Mark I

In January 1943 an M.A.P. Technical Mission visited the U.S.A. to discuss development of a glide path landing system. The main objects of the visit were, to specify the technical requirements for a system for common use in the U.S.A. and the United Kingdom, to discuss possible future developments of instrument landing systems, and to see if the U.S.A. authorities had any valuable new ideas for landing systems.[3] The mission received very favourable reports from Navy and Army pilots of Ground Controlled Approach, and, after attending demonstrations, considered that, although it was not suitable for completely blind landings, it appeared to be the most efficient existing system. The opinion was confirmed by four R.A.F. pilots from the B.A.C. who, in February, practised G.C.A. approaches; only two were beam approach specialists, the others were not in regular flying practice.[4] The favourable reports made by the M.A.P. Technical Mission and the B.A.C. pilots were studied with great interest at the Air Ministry because of the recent investigation into S.B.A.; Air Staff policy towards existing approach systems would obviously be influenced if there was an effective alternative method available.[5] There were, however, some doubts and the R.A.F. Delegation was requested to supply more information and to assure the Air Ministry that the alleged superiority of G.C.A. over other systems was not exaggerated. To prove its worth and to allay doubts Service trials were necessary and the B.A.C. recommended to the U.S.A. authorities that the equipment should be sent to the U.K. with its operating crew so that trials might be carried out with the R.A.F. and the U.S. Eighth Air Force. In

[1] A.M. File S.87187.

[2] A.M. File S.87187.

[3] The Technical Mission consisted of Mr. R. E. Gray of the Radio Department, Royal Aircraft Establishment, Mr. J. E. Clegg of the Telecommunications Research Establishment and Squadron Leader R. J. Falk of the R.A.E.

[4] A.M. File S.89814.

[5] A.M. File C.80491/46.

March 1943 General McLelland agreed to send the laboratory model, known as G.C.A. Mark I, on the understanding that it was to be used for operational trials and not for experimental work.[1] A military operating crew and some of the Radiation Laboratory personnel would accompany it. The equipment could not be made available for shipment to the U.K. before June 1943 as it was being used by the Radiation Laboratory to test new electronic scanning and display arrangements which were to be incorporated in G.C.A. Mark II, then being produced by the firm of Gilfillan.[2]

On 15 March 1943 a panel was formed to make arrangements for the trials.[3] Its terms of reference were '. . . to make all necessary arrangements so that the G.C.A. equipment on arrival in the U.K. can be used immediately for operational trials for aircraft and crews of R.A.F. Bomber Command, R.A.F. Coastal Command, R.A.F. Fighter Command and R.A.F. Army Co-operation Command . . .' The Royal Aircraft Establishment was asked to release Mr. R. E. Gray for attachment to the Directorate of Communications Development at the Ministry of Aircraft Production so that he might act as technical co-ordinator.[4]

Originally Holme on Spalding Moor was suggested as the most suitable location for the trials but in April 1943 Elsham Wolds was chosen and arrangements were made for G.C.A. to be despatched there on its arrival from the U.S.A.[5] The airfield at Elsham Wolds was suitable because it was equipped with Drem Mark II and contact lighting, and S.B.A., so that flying in bad weather was practicable.[6] Considerable care was taken over the allocation of R/T frequencies because the success of the new system depended to a very large extent on the efficiency of R/T communication between aircraft and the controller. The frequencies 5005 and 5280 kilocycles per second were allocated as special G.C.A. frequencies; 5135 kilocycles per second was allocated for communication between the airfield controller and aircraft before they were handed over to G.C.A. control; 6440 kilocycles per second for Bomber Command 'Darky' and 2410 kilocycles per second for Coastal Command 'Darky'.[7] All aircraft taking part were fitted with I.F.F. Mark III, Mark IIIG or Mark IIIGR.

The trials were conducted from 26 July to 23 August under the direction of the Deputy Director of Aircraft Safety, and were attended by Dr. Alvarez and other scientists from the Massachusetts Institute of Technology to see how the equipment worked in operational conditions and to supervise its operation and servicing. Over 300 approaches were made with all types of

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[1] A.M. File S.89814.

[2] A.M. File S.89814.

[3] The chairman was the Deputy Director of Aircraft Safety. He was assisted by the Deputy Director of R.D.F. and a member of the Directorate of Communications Development. (A.M. File S.89814).

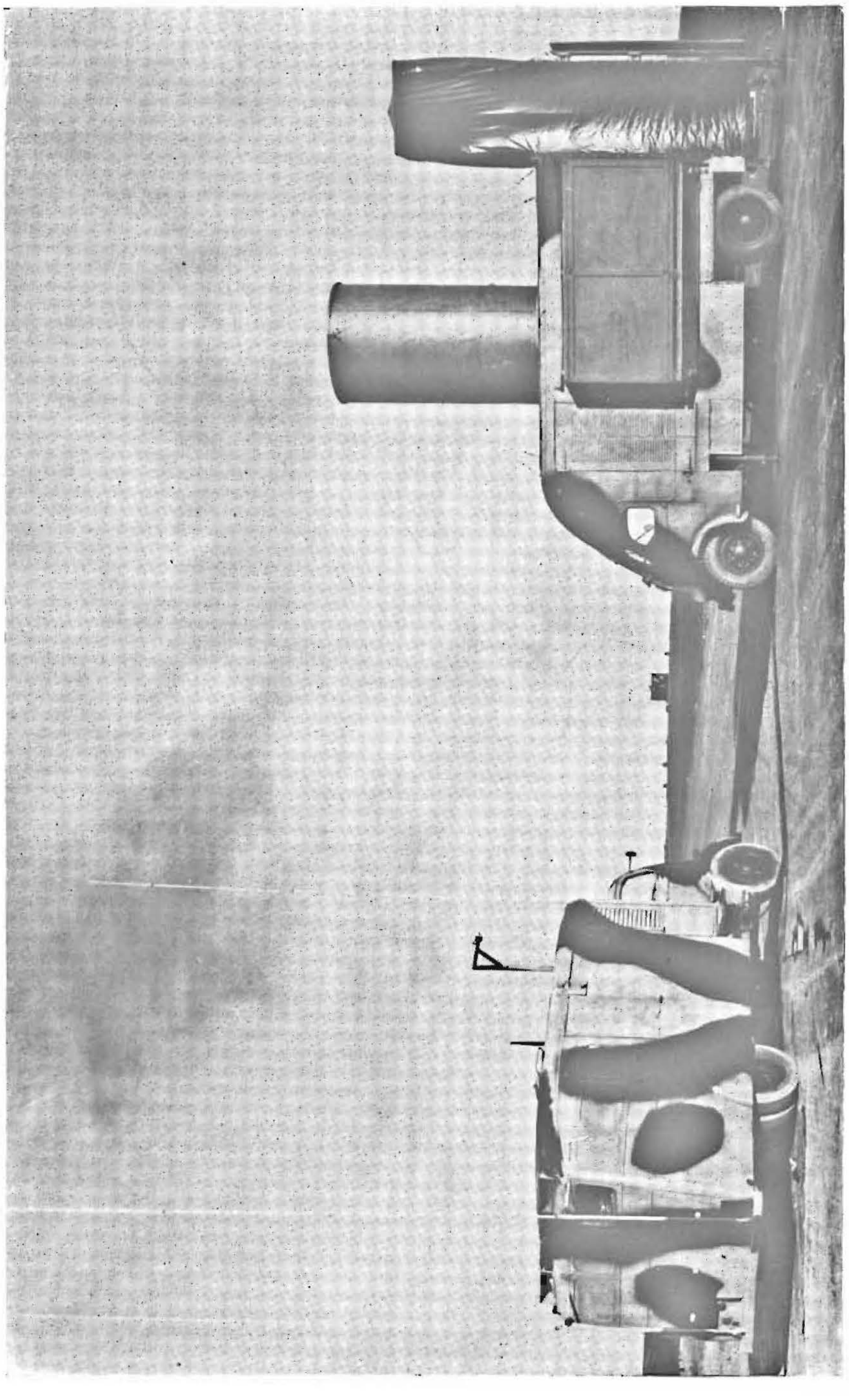
[4] A.M. File S.89814.

[5] A.M. File S.89814.

[6] *Drem Lighting.* Lights were spaced at intervals of 100 yards and were screened from above. They were visible only up to an angle of approximately 11 degrees from the horizontal. The system was installed as a normal flying aid in clear weather. It was simpler and a more economical installation than the contact system.

Contact Lighting. Consisted of sunken lights, spaced at intervals of 50 feet on each side of a beam runway. When visibility was 100 feet two lights could be seen ahead from any selected light point. The system was satisfactory in visibility conditions as low as 30 yards but required quick response from the pilot. The lights were not screened from above so the system could be used only in thick overcast conditions for reasons of security.

[7] A.M. File CS.19359.,



G.C.A. Mark I

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aircraft and individual flights were made by pilots of all ranks, none of whom had used the system before.[1] American pilots also took part and representatives of the Admiralty Signals Department and the Admiralty Signals Establishment were present.[2]

The trials were conducted in three phases. The first part consisted of tests with various types of aircraft to ascertain their flying qualities under G.C.A. control;[3] the second part was composed of tests to determine the speed at which numbers of aircraft could be handled and the point at which they were to come under G.C.A. control; the third phase consisted of the approach control of Lancaster aircraft of No. 103 Squadron on return from operations. From the first stage of the trials, it was clear that the method of approach by G.C.A. would vary with each type of aircraft; this meant that it was essential for the controller to have considerable flying experience himself and to know what type of aircraft was coming in. The second stage of the trials was occupied with the particular problem of Bomber Command, that of landing a large number of aircraft safely in as short a time as possible. 44 approaches were made, 33 of which were successful; the average rate of landing was three every nine minutes. The lesson learnt from this stage was that a satisfactory procedure for feeding aircraft to the control point would have to be found to obviate delay in the landing approach. It was concluded that twice as many landings in bad weather were possible as with S.B.A. because G.C.A. could bring the aircraft to the boundary of the airfield, from where the pilot landed visually.[4] For the third stage of the trials pilots were given no training on the new system and no special briefing, other than a short explanation. 20 Lancaster aircraft returning from operations on the night of 22/23 August 1943 were landed under G.C.A. control, and 17 successful approaches were made. The result showed that even with G.C.A. it was not possible to land large numbers of aircraft quickly when they arrived at the airfield at the same time, but G.C.A. was no slower than other methods.[5] During the trials three communication channels were used; one by the G.C.A. controller and two by the P.P.I. operators. Five aircraft could be handled simultaneously; three by the first P.P.I. operator, one by the second, and one by the G.C.A. controller. If more than three aircraft were seen on the P.P.I. at the same time serious identification and control problems arose. A means would have to be found of controlling the aircraft round the airfield circuit, identifying the aircraft as they approached, and feeding them into the G.C.A. system.[6]

Appreciation of G.C.A. Mark I

The main advantages and disadvantages of G.C.A. when in operational use emerged from the trials. One great merit of the new system was its flexibility. It was mobile and contained its own power supply, and so could be moved from one runway to another when the wind direction changed. It could be used in all weathers in conjunction with the normal airfield flying control organisation; aircraft could approach from any direction. The fact that no aircraft equipment other than an R/T installation was required was of benefit in several ways; there was no heavy installation to increase weight, the system could be

[1] A.M. File CS.19359. [2] A.M. File S.89814.

[3] Tests were made with Spitfire, Typhoon, Mosquito, Master, Oxford, Anson, Liberator, Halifax, Stirling, and Lancaster aircraft.

[4] A.M. File S.87187. [5] A.M. File S.87187. [6] A.M. File CS.19359.

applied to all aircraft and so could become standard for all commands, pilots were accustomed to R/T and were practised in its use. Responsibility for the whole approach up to a short distance from the runway rested with ground personnel so that aircrew were relieved of the strain of concentrating on yet another set of instruments in order to land in bad weather. This was particularly helpful to crews returning from operational flights. The ground controller had an accurate picture of the position of the aircraft in range, elevation, and azimuth, and pilots merely followed his instructions, knowing that flying errors would be corrected from the ground. No special aircrew training was required. Since communication between aircraft and ground was by two-way R/T, the G.C.A. controller was made immediately aware that the system was in use. Servicing was simplified to some extent because all the vital radar components were readily accessible on the ground.[1]

A problem was raised by the necessity of multi-channel R/T; until V.H.F. R/T was introduced into the R.A.F. on a widespread scale, the existing H.F. R/T organisation limited the number of G.C.A. sets which could be installed in one particular area. The manning of the ground crews was also likely to be a problem. Although G.C.A. did not necessitate specialised aircrew training, the ground crews, both operating and servicing, required a very high standard of selection and training, since the control crew were entirely responsible for the safe approach of aircraft. Training would be long and intensive and controllers would have to be carefully selected, with great attention being paid to their personal qualities and previous experience. Expert servicing was also required to keep the equipment effective as G.C.A. was one of the most complex radar equipments then evolved.[2] As the only means of conveying instructions was by R/T, there was a language problem in dealing with foreign pilots. There was no device inherent in G.C.A. Mark I which enabled the ground crew to identify the aircraft under their control. An ancillary system was needed and during the Elsham Wolds trials I.F.F. was used. The identification requirement was two-fold; identification of an aircraft when it first approached the vicinity of the airfield, and its identification when it was handed over from the traffic controller to the approach controller.[3] Various methods were tried and G.C.A. Mark II included facilities for the separate installation of an I.F.F. system. In February 1944 the provision of a D/F loop was suggested.[4] A report received from the U.S.A. in May 1944 revealed that a fairly useful grid map system to facilitate identification had been developed.

The trials made it clear that a very efficient R/T communication system was essential for successful operation. A minimum of three channels was required. It was estimated that the minimum geographical separation between stations operating on the same frequency would have to be at least 60 miles to avoid mutual interference. To equip all airfields in Bomber Command 180 channels would be needed. As the number of additional channels available in the standard H.F. R/T equipment was not more than ten the number of airfields at which G.C.A. could be used was very limited. If the number of stations was not more than five in any one area of a radius of 30 miles, and if the local flying control frequency of each was used for G.C.A., 17 to 20 airfields could be equipped in Bomber Command and 35 to 40 in the rest of the United Kingdom. When

[1] A.H.B./ID4/257. Radio Aids to Flying Control.
[2] A.M. File S.95191. [3] A.M. File CS.19028. [4] A.M. File G.30491/46.

V.H.F. R/T was brought into general use in the R.A.F. the situation would be eased.[1] Stations would then have to be 120 miles apart but the number of channels available would be larger. If 90 kilocycles per second spacing on the V.H.F. band were accepted 90 stations in Bomber Command could be equipped, provided that density of stations was not more than 46 per area of radius 60 miles. In the rest of the country 200 airfields could be equipped. By careful selection a fairly continuous G.C.A. service could be set up. Eventually the problem of R/T communication did not become so pressing as was at first feared because the production of G.C.A. equipment in the U.S.A. was very slow and not more than 60 reached the United Kingdom before the end of the war with Germany.[2]

Air Staff Policy

On 23 September 1943 when a conference was held to discuss radio aids to flying control, it was stated that requirements varied within commands; the main need in Bomber Command was a system which would assist in speeding considerably the landing rate of large numbers of heavy aircraft arriving at an airfield within a short time of each other, while Fighter and Coastal Commands needed a system by which aircraft in much smaller numbers could be assisted to land safely in all weathers with less emphasis on the time-factor. The principles governing the choice of an approach system were the amalgamation of the bad weather system with the normal flying control procedure, the reduction of strain on the pilot and crew by assistance from the ground, a standard system for all commands, the provision of immediate assistance to aircraft in distress, and mobility of equipment. Three systems were discussed: Standard Beam Approach and the Beam Approach Beacon System, both of which required a radio glide path indicator for full presentation, and Ground Controlled Approach. The last was considered to be the best available, but could only be introduced in limited quantities because of the need for multi-channel R/T and because of the heavy manpower requirement. The committee recommended that it should be adopted on as wide a scale as possible and that B.A.B.S. should be employed where the use of G.C.A. was impossible.[3]

On 5 November 1943 a conference was held at the Air Ministry, to decide the future policy for the use of radio aids for flying control in all commands. The Deputy Chief of the Air Staff was chairman, the Inspector-General was present, and all the operational commands were represented. It was agreed that G.C.A. was practicable, provided that R/T communication was good. As a firm decision on its introduction into the R.A.F. was required before equipment could be obtained from the U.S.A., it was decided that G.C.A. should be employed as it became available, that most aircraft would have to use B.A.B.S. in the meantime, and that the use of S.B.A. would be gradually discontinued. No difficulty in providing and training ground crews for G.C.A. was anticipated.[4] Production of G.C.A. in the United Kingdom was at no time considered to be a practicable proposition; reliance was placed on production in the U.S.A. and the outcome of the operational trials was awaited before a large-scale production plan was formulated. Early in 1943, however, small orders were placed with American firms; 10 equipments were ordered from the firm of Gilfillan, and the U.S. Navy placed a contract with Bendix for 15.[5] On 2 November 1943 the R.A.F.

[1] It was thought to be unlikely before the end of 1945. (A.M. File CS.19028).
[2] A.M. File CS.19028. [3] A.H.B./ID4/257. [4] A.H.B./ID4/257.
[5] T.R.E. File D.1293.

Delegation informed the Air Ministry that the U.S. Army had ordered 10 G.C.A. Mark II and 47 Mark III from Gilfillan; three of the Mark II equipments were earmarked for the R.A.F. The U.S. Navy had ordered 20 G.C.A. Mark II from Bendix and might allow the R.A.F. to have 12 of these if it could be proved that G.C.A. was urgently required for operations in the U.K. The R.A.F. Delegation required a firm operational requirement so that bids could be made for the requisite number of equipments.[1] Later in November, when G.C.A. had been accepted as the primary approach aid for the R.A.F., the Air Ministry stated that full details of requirements had not been worked out but that 500 seemed to be a likely figure.[2] On 8 February 1944 the Ministry of Aircraft Production gave the British Air Commission full details of United Kingdom requirements. Production of S.B.A. was to be discontinued and the immediate requirement for G.C.A. was 175; the blind approach policy in the R.A.F. depended on whether sufficient equipment could be obtained from the U.S.A.[3] Although the urgency of the requirement was repeatedly emphasised production of G.C.A. was very slow because only limited manufacturing facilities were available. In May 1944 the Gilfillan contract was split with the firm of Federal in an effort to hasten delivery but supplies of G.C.A Mark II did not begin to arrive in the United Kingdom until 23 June 1944, and by the middle of August only five had arrived.[4] In June 1944 Headquarters Bomber Command after a careful study of the more recent reports on G.C.A., together with a comparison of its advantages and disadvantages, reduced the requirement for G.C.A. to 15 installations throughout the command as it was apparent that G.C.A. did not meet the most urgent need, that of a system for safely landing large numbers of aircraft quickly. This change in opinion of the chief user of G.C.A., in combination with the difficulties of production and frequency allocation, led to a modification of the original policy, officially expressed in September 1944, when it was decided that B.A.B.S. Mark II was to become the standard approach system throughout the operational commands of the Royal Air Force. G.C.A., in conjunction with FIDO, was to be installed at suitably geographically spaced airfields for use when B.A.B.S. Mark II aircraft equipment was unserviceable or when aircraft had to be landed in an emergency in worse weather conditions than visibility 1,000 yards and cloud ceiling 200 feet. The slow rate of production of G.C.A., the wide separation of airfields at which it could be used necessitated by the inadequate number of R/T channels available, and the limitation of manpower resources, all meant that the original number of equipments required had to be drastically reduced.[5] Thus the conception of G.C.A. as the primary approach system was altered; instead it was regarded as a supplementary aid, to be used in emergency only.[6]

Development of G.C.A. Mark II

As a result of the trials of the first laboratory model of G.C.A. certain improvements were incorporated in the production equipments made by the firm of Gilfillan. The method of housing the equipment in two vehicles had caused delays when G.C.A. Mark I had to be moved from one runway to another. The uncoupling of the power supply vehicle from the control vehicle meant that the valves and cathode ray tubes in the second vehicle cooled down and a long

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[1] A.M. File C.30491/46. [2] A.M. File C.42741. [3] A.M. File C.42741.
[4] A.M. File CS.19028. [5] A.M. File S.94422. [6] A.M. File S.97074.

wait was necessary in the new position after the power supply was switched on again before they were ready for use.[1] G.C.A. Mark II was housed in a four-ton six-wheel prime mover which contained air conditioning equipment and two 7½-kilowatt petrol-electric generators, and a trailer which contained all the radar and communications equipment.[2] This lessened considerably the delay caused by a move between runways as the valves and tubes remained at their working temperature while the vehicles were in motion. Modifications were also incorporated in the radar equipment. The precision aerials were no longer rotated with the entire array and reflector; the beam was scanned electrically by phase-changing in the wave-guide itself. Higher scanning rates could be used and considerable elimination of ground returns was effected. Expanded sector plan position indicators replaced the angle-range scopes for the display of azimuth and elevation information; two for azimuth, with ranges respectively of 10 and 2 miles, and two similar indicators for elevation. Both azimuth and elevation paths appeared as straight lines so that linear distances could be obtained directly from the cathode ray tube. The controller was located between the azimuth and elevation P.P.I. operators so that he could see their displays in addition to his own error meters. This gave him a more realistic picture of the approach.[3] The cathode ray tubes were placed at an angle of 45 degrees facing downwards and were viewed indirectly in a mirror. This method of viewing lessened eye strain because it prevented the operator from peering too closely at the screen. Maps or charts could be placed beneath the mirror. There were other alterations. No range operator was required. A mechanical marker set on the aircraft signal was used to compute deviations from the approach path. This allowed more rapid alignment than the electrical marker of G.C.A. Mark I. There was still no means of identifying aircraft but the specification for the trailer included the provision of a cable termination for power, telephones, and synchronising pulses in order that a separate I.F.F. system might be attached if required.[4]

G.C.A. Mark II made by Bendix followed the same general functional design as the original Mark I laboratory model and embodied the same main improvements as those incorporated in the Gilfillan Mark II equipment. There were, however, some differences. The Bendix design placed the air conditioning equipment entirely in the operating trailer, while the main power system, including the regulator for the auxiliary supply, was in the prime mover. There were differences in the materials of which the equipment was made, and some minor differences in the technical construction. A noise limiter was added to prevent interference with the V.H.F. communication equipment. In February 1944 Dr. A. G. Touch, of the British Air Commission, had visited the Gilfillan factory and reported that with G.C.A. Mark II there was considerable interaction between the radar and communication equipment because they were both housed in the trailer and no action had been taken to prevent interference. The radar was not screened, none of the leads carrying pulses were shielded, and no filters were incorporated. He considered that the Gilfillan factory and engineering staff were too small to cope with the problems of production of such a complex piece of radar equipment. The Bendix model appeared to be more satisfactory and the engineering staff of the firm were more able to cope with the problems. As a result of the operational trials of G.C.A. Mark I technical

[1] A.M. File S.87187. [2] A.M. File S.95191. [3] A.M. File S.87187.
[4] A.M. File S.95191.

officers from the R.A.E. had drawn up a list of requirements in November 1943 for later Marks. These were checked by the engineering staff of Bendix, who tried to incorporate the British suggestions. Where they were unable to do this they had devised satisfactory alternatives.[1]

G.C.A. Marks III and IV did not differ very much from Mark II. Mark III differed in that the precision radar equipment operated on a wavelength of 3·3 centimetres instead of 3·2, and Mark IV was merely an improved version of Mark III. Towards the end of the war development was begun of a system known as 'Split G.C.A.' in which the control equipment was installed in the airfield control tower whilst only the precision equipment was required to be mobile.[2]

G.C.A. Training

The original laboratory model of G.C.A. Mark I was retained in the U.K. for further operational trials and for the training of crews, so that when the first Mark II production equipments were received they could be put into immediate operational use. The equipment was moved from Elsham Wolds in August 1943 to Davidstow Moor and from there to St. Eval in September for Coastal Command trials.[3] The crew who had accompanied the equipment in the summer remained with it in order to train a crew consisting of one R.A.F. sergeant, one R.A.F. corporal and four A.C.W. W.A.A.F. radar operators so that they could take over operation of the equipment when the Americans left.[4] The trials were not as successful as those at Elsham Wolds, partly because at St. Eval all approaches were carried out under a hood whereas at the first trials this was not done, and partly because the equipment was badly affected by wear and tear. On 8 October 1943 the last of the original G.C.A. crew returned to the U.S.A. and the problem of servicing grew more and more acute. Although crew training was continued it was often interrupted because the equipment broke down.[5] In January 1944 Headquarters No. 26 Group were made responsible for the technical efficiency of the equipment, and on 14 March 1944 they advocated its removal to the Signals Development Unit at Hinton-in-the-Hedges. The necessity for thorough training had been emphasised by difficulties experienced with S.B.A., and it was agreed that this equipment should not be used operationally but should be used only for training and for the investigation of operational problems; a busy operational airfield was not therefore a suitable location.[6]

In addition to servicing personnel, highly skilled controllers were needed, both to inspire confidence in the pilots and to extract the utmost from the equipment. The effectiveness of the system was increased by good operators; at Elsham Wolds aircraft were brought down to within 440 yards of the runway but by the time the equipment was under the control of less experienced operators at St. Eval this distance was increased to half a mile.[7] In May 1944 it was agreed that a G.C.A. school should be set up and Hinton-in-the-Hedges was recommended as the location if suitable accommodation could be provided.[8]

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[1] A.M. File C.30491/46. [2] A.M. File C.20565/46. [3] A.M. File S.89814.

[4] A.M. File C.30491/46. A team consisting of one officer, one sergeant, and three aircraftmen was also sent on a course at the Gilfillan factory in Los Angeles in July 1943. It returned to the U.K. in June 1944 for duty at the G.C.A. school.

[5] A.M. File CS.20588. [6] A.M. File S.89814. [7] A.M. File CS.20588.

[8] A.M. File S.94422/43.

A large training school was required since it was estimated that 123 crews would need to be trained by the end of 1945: eight by the end of 1944 and 10 crews per month in 1945.[1] At the end of June 1944 Headquarters No. 26 Group suggested that another airfield be transferred to the group to accommodate the Signals Development Unit and the G.C.A. wing because the major works services required at Hinton-in-the-Hedges would take a long time to complete and the G.C.A. training school was an urgent commitment. In July 1944 Honiley was chosen as the location of the Signals Flying Unit, which was to incorporate the Signals Development Unit, previously at Hinton-in-the-Hedges, the new G.C.A. wing, and a servicing wing.[2] It had been proposed that a combined G.C.A. training school for the U.S.A.A.F., U.S.N., R.A.F., and R.C.A.F. should be established in the U.S.A. but this was rejected by the G.C.A. panel on the grounds that crews had to be trained quickly and training had to be linked with operational procedure in the United Kingdom. Liaison with other Services could be achieved by the exchange of instructors and information.

In June 1944 the composition of a G.C.A. crew was decided. The crew captain, who would also act as relief controller, was to be a squadron leader with considerable flying experience on many types of aircraft, and was whenever possible to be a pilot who had completed an operational tour of duty. The radio navigation officer, who would also act as relief director, was to be a flight lieutenant with operating experience of aircraft radar equipment. Two approach controllers of the rank of flight lieutenant were required to guide the aircraft down the approach path. Officers with pilot's qualifications were preferable for this task, but if these were not available men with experience of flying control and G.C.I. duties were recommended. Four flight sergeant directors were required for the initial approach stage; selection from aircrew N.C.Os. with operating experience of aircraft radar was recommended. Finally five W.A.A.F. aircraftwomen radar operators were required for employment as trackers. The composition of a servicing crew was one flight sergeant, one sergeant, two corporals, and two aircraftmen radar mechanics and two M.T. drivers or fitters. A crew of this size would be sufficient to man one unit for 8 to 12 hours operational use each day.[3] A high standard was required from both operating and servicing crews for the successful introduction of G.C.A. into the Service. Headquarters No. 26 Group was made responsible for the selection of suitable personnel for G.C.A. training.[4] When, in November 1943, the decision to adopt G.C.A. had been made, no manpower difficulty was anticipated, but in the event it proved to be very difficult to find sufficient

[1] Estimated requirements were:—

Bomber Command	15
Coastal Command	17
Transport Command	16
A.E.A.F. (including A.D.G.B.)	25
Flying Training Command	10
Overseas	30
	113
Reserve	10
	123

[2] A.M. File S.101140. The establishment for the G.C.A. training unit was eight Oxford, eight Wellington and two Lancaster aircraft, and 38 officers and 250 other ranks.

[3] A.M. File S.94422/43.

[4] A.M. File S.101140.

personnel of the high standard and the experience required and amongst the suggestions put forward were the reduction of B.A.T. flights, the closing of the Flying Control and Airfield Controller School at Watchfield, the reduction of the home radar chain, and the disestablishment of all airfield controllers.

The five G.C.A. Mark II equipments received in the U.K. were used for training, which began at Honiley on 1 October 1944 with three crews under instruction. The equipment, as had been foreseen, was from Gilfillan production and was not very satisfactory, considerable modification being necessary. At the end of July 1944 a G.C.A. trainer, constructed from two trainers Type 29 and a C.H.L. receiver by R.A.F. and T.R.E. personnel, was despatched to Honiley; a trainer had been ordered from the firm of Gilfillan but its development was very slow and it did not reproduce operational conditions sufficiently well for satisfactory training.[1] In November 1944 it became apparent that Honiley was not a suitable location for the G.C.A. training unit because extensive works services were required and labour was very difficult to obtain. Stratford was considered a suitable alternative and in March 1945 the G.C.A. training school was moved there. The S.F.U. remained at Honiley and was responsible for the administration and supervision of training. During the winter of 1944/45 the training programme outstripped the production programme, and by the time the school moved five trained crews were awaiting the arrival of equipment. In April 1945 three Bendix models were received and were allocated to the school at Stratford.

Operational Use of G.C.A. Mark II

G.C.A. was put into operational use by the R.A.F. for the first time when, in February 1945, a Mark II equipment and crew were taken from the school and transferred to Epinoy for use by aircraft of 2nd T.A.F. By the middle of April over 100 G.C.A. approaches had been made, and Headquarters 2nd T.A.F. reported very favourably on the system, stating that its accuracy had overcome the normal prejudice against control from the ground. A requirement was stated for more equipment and crews in north-west Europe. Such a favourable opinion in the first command to use G.C.A. operationally influenced a reallocation of available equipment and personnel. A further six Bendix production sets arrived in the U.K. in May 1945, and by October G.C.A. was in operation at six airfields: Lyneham, Prestwick, Melsbroek, Wunsdorf, Fuhlsbuettel, and Schleswig. At Prestwick it was used continuously by the Transport Command All-Weather Flight, including occasions when visibility was between 50 and 500 yards and cloud-base down to between 50 and 150 feet. The highly-specialised aircrews showed great faith in the system, which was at its best when used with single aircraft only.[2]

In September 1945 the Air Traffic Control Practices Committee submitted to the Air Council a report on the use of radio navigational systems in bad weather. It was considered that G.C.A. was the best existing approach system because it was the simplest for aircrew to use although its operation and servicing required highly-skilled personnel on the ground. A recommendation

[1] A.M. File C.43429/51.

[2] M.A.P. File SB.41807, Part II. G.C.A. was almost ready for operational use at Manston, St. Eval and Bassingbourn, and three more equipments had been allocated to Carnaby, Valley and a site to be chosen by Headquarters Transport Command.

was made that it should be used in conjunction with V.H.F. R/T to provide a common-user safety service for all types of aircraft. However, the actual use of G.C.A., and SCS. 51, was limited by the fact that only a small number of equipments could be purchased from the U.S.A. after the cessation of the Lease-Lend agreement, and by the wastage of trained crews caused by demobilisation.

Description of SCS. 51 System

SCS. 51 was the short title given to an approach aid known as the American Air Forces Instrument Approach System.[1] It was first used by the U.S.A.A.F. in the summer of 1943, and by August 1943 the system was installed or undergoing installation at all stations along the Army Airway from Mitchell Field, New York, to Gander Lake, Newfoundland. During September and October American O.T.Us. were also equipped.[2]

The installation consisted of a localiser for guidance to the runway, markers to fix position along the approach path, and a glide path to provide information as to the correct line of descent from 10 miles to the point of contact on the runway. The localiser was of the two-course visual type, furnishing a line of guidance down the centre line of the runway. The heading was produced by overlapping modulation patterns of 90 and 150 cycles per second which were selectively filtered and differentially rectified in the aircraft receiver to actuate the vertical needle of the cross-pointer indicator. Six frequencies were available in the band 108·3 to 110·3 megacycles per second, and radiation was horizontally polarised. It was installed in a 2½-ton vehicle and power was supplied by a self-contained three-kilowatt petrol-electric set. The localiser vehicle was normally placed 750 feet from the end of the runway opposite to the approach direction. The glide path was of the equi-signal straight type, provision being made for adjusting the descent path to any angle between two and five degrees. The glide path in space was produced by overlapping signal patterns modulated at 90 and 150 cycles which were filtered and rectified in the aircraft to indicate its position with respect to the path by movement of the cross-pointer indicator. The glide path employed a single-channel carrier frequency of 335 megacycles per second. The glide path transmitter was installed in a two-wheeled trailer which was normally sited 400 feet off the runway centre line approximately 700 feet in from the approach end of the runway. There were three marker beacons which operated on a carrier frequency of 75 megacycles per second. The boundary marker was placed at the edge of the usable area of the airfield; it was not keyed. The middle marker was situated 4,500 feet from the approach end of the runway; it was keyed at two dashes per second. The outer marker was placed three and a half miles from the middle marker; it was keyed at six dots per second. The equipment was towed and transported in a quarter-ton vehicle, three of which were supplied with the system. The aircraft equipment for use with the SCS. 51 system consisted of an aerial array, transmission line and fittings, a localiser receiver, a glide path receiver, a marker beacon receiver, a pilot's control box and a cross-pointer indicator. The aerial array included a U-shaped folded dipole mounted on a mast, nine inches in height, for localiser reception, and a straight dipole mounted just forward of the U on the same mast for reception

[1] A.M. File S.96994.

[2] A.M. File CS.21021.

of glide path signals. The localiser receiver was of the superheterodyne type and provided six crystal-controlled channels. The glide path receivers were of two types—super-regenerative and crystal-controlled superheterodyne. Early types were single-channel. The control box was approximately two and a half inches square and was located within reach of the pilot. The cross-pointer indicator was of standard instrument size and was mounted on the instrument panel. The vertical needle of the indicator was pivoted at the top of the face and moved right or left to indicate the position of the localiser course with respect to the aircraft. The horizontal needle of the indicator was pivoted at the left and swung up and down to indicate the position of the glide path with respect to the aircraft. The intersection of the needles represented the proper flight line in space and the entire instrument when inbound for a landing was flown by 'follow the needle' sensing. If the intersection was to the left of and above the centre of the instrument then the desired flight path was above and to the left of the aircraft. The marker beacon receiver was a simple tuned RF and detector system feeding through a rectifier to a relay which operated an indicator light on the instrument panel.[1]

Trials in the United Kingdom of SCS. 51

In September 1943 the Britain Air Commission informed the Ministry of Aircraft Production that the U.S.A.A.F. authorities were very anxious to test SCS. 51 in the United States Eighth Air Force in operational conditions in the United Kingdom. It was therefore suggested that the equipment be sent to the U.K. for joint tests between the R.A.F. and the Eighth Air Force. The Air Ministry agreed to the proposal but stipulated that experimental trials, under Ministry of Aircraft Production arrangements, rather than Service operational trials, were to be held.[2] One ground and six aircraft installations despatched from the U.S.A. especially for the trials arrived in the U.K. in the middle of January 1944. Concurrent British and American trials were held at the Telecommunications Flying Unit, Defford, from 5 February to 4 March 1944. The aircraft equipment was installed in U.S.A.A.F. Fortress and Liberator aircraft and in R.A.F. Lancaster, Stirling, Wellington and Oxford aircraft. During the early stages of the trials visibility was about 1,000 yards or less and on one day tests were made by three pilots in a snow-storm, when flying by accepted standards, even with the assistance of S.B.A., would have been prohibited. The R.A.F. aircraft made 70 approaches, 26 hooded and 44 open, and the equipment in general proved to be very reliable. The localiser failed once during flight but for less than five minutes and neither the glide path nor the aircraft equipment failed. The airfield boundary marker was unreliable, but the general performance of the equipment was good. At 1,000 feet the localiser range was approximately 25 miles and the glide path range 15 miles, range being increased with height. The conclusion reached as a result of the trials was that SCS. 51 was a reliable system of instrument approach and one easy to learn. It was considered that a pilot of average ability would thoroughly grasp the system in two hours' flying instruction and that the amount of training required was considerably less than for any other pilot-operated system.[3]

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[1] A.M. File CS.21021.

[2] Because of this the personnel engaged on the trials were confined to those of the R.A.E. and T.F.U. (A.M. File CS.21021.)

[3] A.M. File S.96994.

Introduction into Service Use

As a result of the joint British-American trials at Defford the U.S.A.A.F. in the United Kingdom decided to adopt SCS. 51 and in March 1944 installations were proposed at 21 airfields. At first there appeared to be no operational requirement for SCS. 51 in the R.A.F. In January 1944 it had been stated at a meeting held to discuss the trials that they were being undertaken for interest only, the Air Staff policy being to use G.C.A. as an approach system. As an interim measure S.B.A. and V.H.F. B.A. were to continue in use, as were the various Marks of B.A.B.S.[1] Further deterrents to the adoption of SCS. 51 lay in the difficulties of obtaining supplies from the U.S.A. and of installing new equipment in aircraft. The T.F.U. report on the trials, however, emphasised that R.A.F. aircraft, particularly in Transport Command, would be able to make good use of the equipment when landing at or operating from American bases.[2] Representatives from Transport Command participated in the trials and on 28 April 1944 Headquarters Transport Command expressed an operational requirement for the installation of SCS. 51 in all transport aircraft and at all terminal airfields, main alternative airfields, and major staging posts. This did not modify the Transport Command requirement for the provision of G.C.A. The view of the command was that SCS. 51 had several advantages over the existing S.B.A. equipment. A positive glide path was provided for the pilot, and presentation was visual and easier to follow accurately than the corresponding aural signals of S.B.A. The ground equipment was mobile and could be moved rapidly from runway to runway. It did not involve installation of extensive permanent ground stations linked up by long underground cables, which were liable to develop faults just when the equipment was most urgently required. The aircraft equipment was light and easy to install and represented an overall saving in weight of approximately 70 pounds compared with the S.B.A. aircraft equipment.[3] Air Ministry opinion was favourably inclined towards the limited use of SCS. 51 in the R.A.F. and in May 1944 official approval was given to the Transport Command proposal that aircraft sets be fitted in all heavy transport aircraft and ground sets installed at all terminals, main alternates and major staging posts. The aircraft involved were York, Dakota, Stirling Freighter, Warwick Freighter, Liberator C.87 and Liberator Marks I and II. The total number of airfields at which installation was planned was 14 in the United Kingdom and 20 overseas.[4]

Installation and Operational Use

The main handicap in the use of SCS. 51 in the R.A.F. was the fact that the supply of equipment was limited to the small amount which could be obtained from the U.S.A. Most of what was manufactured there was required for the U.S.A.A.F., which had adopted the system as its main approach aid in all theatres. The Ministry of Aircraft Production submitted a tentative request for 70 ground and 1,000 aircraft installations but in June 1944 the British Air Commission stated that there was little possibility of obtaining bulk supplies of SCS. 51 from the U.S.A. in 1944. As a result the Air Ministry assessed the immediate needs of Transport Command at 100 aircraft and six ground installations.[5] The shortage of supplies meant that installation of SCS. 51

[1] A.M. File CS.21021.
[2] A.M. File S.96994.
[3] A.M. File CS.22388.
[4] A.M. File CS.21021.
[5] A.M. File C.29698/46.

in the United Kingdom was very slow. In April 1944 the experimental equipment was moved from Defford to Bovingdon for use by the United States Air Transport Command.[1] At the same time the Bovingdon installation was used to enable comprehensive tests to be carried out by the R.A.E. to investigate the degree to which mutual interference might be experienced between SCS. 51 and V.H.F. R/T. It had been feared earlier that the localiser signals would interfere with V.H.F. R/T because the localiser transmitted in the Fighter Command frequency band; frequencies were not identical but a serious problem of adjacent channel interference was anticipated. As a result of observations at the Defford trials, however, the T.F.U. and Headquarters A.E.A.F. had reported that the chances of interference between localiser and V.H.F. channels would be small providing sufficient care was taken in the allocation of localiser frequencies.[2] This danger of mutual interference meant that the frequency allocations for all proposed SCS. 51 installations in the United Kingdom, both R.A.F. and U.S.A.A.F., had to be submitted to the Air Ministry for approval before the equipment was installed.[3]

During the winter of 1944/45 three SCS. 51 installations were completed by the U.S.A.A.F. for Transport Command at Prestwick, Valley and St. Mawgan. These were the only R.A.F. ground installations in operational use during the war in Europe and were considered to be very satisfactory. During 1945 a few SCS. 51 aircraft sets were received and were fitted in Transport Command aircraft.[4] After the first three aircraft installations had been made by the U.S.A.A.F., Headquarters No. 26 Group was made responsible for all R.A.F. siting, installation and servicing, and the first SCS. 51 ground installation allocated to the United Kingdom was retained at the Signals Flying Unit, Honiley, for No. 26 Group experimental purposes. During the summer of 1945 larger supplies began to arrive in the United Kingdom and installation plans went ahead. On arrival sets were sent to the S.F.U. for checking and to enable 26 Group personnel to familiarise themselves with the equipment.[5] One problem the R.A.F. had to contend with in the operation of SCS. 51 was the manpower situation. When supplied from the U.S.A. all items of the ground equipment—localiser beacons, glide path beacon, and three marker beacons—were powered by separate petrol-electric generating sets and therefore each required an attendant while in operation. The U.S.A.A.F. was able to provide the necessary manpower but it was impossible for the R.A.F. to do so. The Air Ministry therefore decided that British installations were to be fitted with remote control and fault indication facilities. As this decision involved more extensive works services than with the American installation existing S.B.A. fittings were to be used as far as possible.[6]

The shortage of equipment affected the SCS. 51 training programme because the few sets which were needed for operational purposes could not be diverted for use in training schools. The U.S.A.A.F. provided the necessary training facilities. In July 1945 two R.A.F. N.C.Os. were given three weeks' instruction on the SCS. 51 installation at Bovingdon by U.S.A.A.F. personnel; they were then posted to the 1406th Army Air Force Base Unit at St. Mawgan to instruct R.A.F. mechanics on servicing the equipment.[7]

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[1] A.M. File A.97774/51.
[2] A.M. File CS.21021.
[3] A.M. File C.29698/46.
[4] A.M. File CS.22388.
[5] A.M. File A.97774/51.
[6] A.M. File C.29698/46.
[7] A.M. File A.97774/51.

The SCS. 51 system proved to be so satisfactory that in November 1945 items of ground equipment were issued to the firm of Pye Radio so that they might develop a British equivalent. In that same month a policy decision on the future installation of SCS. 51 was reached. Ground equipment, either American or the British civil version, was to be installed, in addition to B.A.B.S. Mark II, only at Transport Command airfields which were in common use with American military or civil aircraft, and British civil aircraft, and at a selected training airfield. Aircraft equipment, in addition to Rebecca Marks II or IV, was to be installed in aircraft which were required to land at American military or civil, and British civil, airfields.[1]

[1] A.M. File C.29698/46.

CHAPTER 19

WIRELESS DIRECTION-FINDING, 1919–1934

Experience gained during the First World War had shown that several forms of wireless direction-finding were practical propositions as aids to air navigation.[1] They included the use of Bellini-Tosi ground stations, of aircraft D/F equipment for obtaining bearings from ground wireless beacons located at known positions, and of aircraft wing coils arranged so that signals of maximum strength were received when the aircraft was heading towards a ground wireless station. Basically they were the systems over which controversy raged during the ensuing fifteen years.[2]

Formulation of Early Direction-Finding Policy

During the war aircraft had made use of the many Admiralty D/F stations with very useful results. However, the siting of the stations, being entirely coastal, was not of great use to the R.A.F. in peacetime, and it is therefore not surprising that the Air Ministry showed little interest in the opening of nine of them to the Mercantile Marine on 1 June 1919, nor in the subsequent proposals for a permanent direction-finding service made by the Imperial Communications Committee of the Committee of Imperial Defence at a conference on 12 May 1921.[3] The proposal that the new peacetime service should be operated by the Post Office was accepted, but before it could be taken over reorganisation was needed, and permanent buildings had to be erected. Trials were begun at Niton, Isle of Wight, in 1921/22 to decide what form the new organisation should take. In view of subsequent experience, reports made as a result of the trials are of interest:—

(a) Under normal conditions bearings accurate to within two degrees could be ascertained by wireless direction-finding apparatus.

(b) Bearings taken at night were subject to a variable error which increased with distance.

(c) The reliable range was about 100 miles in daytime and 50 miles at night.

(d) A D/F station when first erected required the co-operation of a ship for calibration, and for maintaining a periodic check on the working of the station, particularly in the event of any modification being made in the apparatus.

(e) The personnel of a D/F station required extended experience in D/F work before undertaking the duty of giving bearings to ships. Special preliminary training was essential.

Research and development was continued at the new Wireless Experimental Establishment at Biggin Hill in the years immediately following the war.[4] A flight test of an aircraft fitted with D/F wing coils was arranged between the

[1] *See* Appendix No. 10 for details of the technical principles of wireless direction-finding.

[2] During this period the aircraft W/T most generally in use was a combination of T.21A and Tf.

[3] A.M. File S.14394.

[4] A.M. File 293488/21.

Director of Research and the Instrument Design Establishment at Biggin Hill in 1920, the co-operation of H.M. Signal School, Portsmouth, and H.M.S. *Antrim* being offered by the Admiralty. Two flights were made in November/December 1920, and successful homing to H.M.S. *Antrim*, situated some miles off the coast, was carried out on each occasion.[1] The R.A.F. was also keenly interested in the development of several other items of D/F apparatus; indeed, the long and somewhat nebulous list on the W/T Research Programme for 1922/23 illustrated the doubt which existed at that time about future D/F policy, although training in wireless D/F had been included in the syllabus of the Navigation School since 1919, first at Andover and then at Calshot. At a meeting held to decide the 1923/24 programme the only system recommended was wing coils, which were still being used for homing purposes and for locating W/T stations generally.[2] But when, in July 1923, the wireless equipment for the navigation of airships from England to Bombay was discussed, it was freely admitted that D/F equipment in airships was still in the experimental stage, and that reliance would have to be placed on obtaining bearings from ground stations. As yet there were no R.A.F. D/F ground stations in England, although there were two at Croydon and Pulham operated on behalf of civil aviation; R.A.F. D/F stations were in existence or being planned in Malta, Egypt, and Iraq.

It had to be decided what forms of radio communication were available for, and would be needed by, Home Defence bombing squadrons. Knowledge and experience available at the Air Ministry were not sufficient to enable a decision to be reached, and as a preliminary to the holding of a conference on 27 November 1923 the views of the Commandant of the Staff College, the A.O.C. Coastal Area, the A.O.C. Inland Area, and the O.C. Central Flying School, were sought.[3] As a result of the conference the Chief of the Air Staff formulated on 19 December 1923 the types of wireless equipment to be installed in existing day and night bomber aircraft and the lines of development to be followed for bomber aircraft of the foreseeable future. Two selected squadrons were to be equipped with two-way W/T and wing coils, and two W/T ground stations were to be established for position-finding; one Vickers Vimy squadron was to be equipped with two-way W/T and with rotating coils for direction-finding if possible; as each of the next three new night-bombing squadrons were formed they were to be equipped with two-way W/T. The shape of future direction-finding policy was outlined in the emphasis laid on the need for development of the revolving beacon method.[4]

Progress during the next three years was retarded by difficulties encountered in the supply and installation of equipment. Manpower and workshop facilities were limited; radio telephony trials were coupled with those of W/T; R/T and D/F in any form were barely out of the experimental stage; most aircraft had never been fitted with wireless and no installation designs or plans were in existence; bonding and screening involved up to 4,450 man-hours in some aircraft; installation involved the design and manufacture of numbers of small parts which had not reached the stage of standardisation. Month by month the Air Staff requirement was increased, and as time went on many modifications became necessary; some because of failures and others because of the advances made in wireless technique between the mock-up stage and delivery of new types of aircraft. Modifications created their own train of procedure delays,

[1] A.M. File 311127/20. [2] A.M. File S.22239. [3] A.M. File S.23185.
[4] *See* Appendix No. 11.

which included the time taken to estimate cost, to raise a contract, and to obtain financial sanction. The Chief of the Air Staff was particularly perturbed about them and caused arrangements to be made so that modifications were embodied, after they had been given due consideration, at stated intervals of about one year, instead of piecemeal.[1] Development of the four main direction-finding systems, rotating coils installed in the fuselage, fixed coils located on the main-planes, rotating beacons, and D/F ground stations, was uneven.

Aircraft Direction-Finding Loops

Although in 1923 opinion generally did not favour the rotating coil system, installation in one Vickers Vimy squadron was completed, but only with great difficulty because of the size of the coils. After some months of trials it was found that technical difficulties made the system impracticable, and it was eventually temporarily abandoned by the R.A.F. Over a period of two years satisfactory results were obtained with the wing coil system. Two squadrons were equipped; No. 100 armed with Fawn and No. 207 with D.H.9A aircraft. Pressure of work prevented installation in replacement aircraft and the trials were discontinued; it was recognised that the system was effective for homing only.

The R.A.E. was requested, in January 1934, to develop a rotating loop for aircraft installation so that trials might be made on the marine beacon wave-band of 290 to 320 kilocycles per second.[2] Late in 1933 Headquarters Coastal Area had raised a requirement for aircraft D/F equipment which would enable attacking aircraft to home to the transmissions of shadowing or reconnaissance aircraft.[3] The loop, with a modified R.68 receiver, was installed in a Vildebeeste of the Coast Defence Training Squadron. Trials included homing to a ground station, maintaining a bearing from a ground station, and obtaining fixes from several ground stations. In September 1934 Headquarters Coastal Area considered that the results indicated that the rotating loop was of value. Meanwhile, however, the R.A.E. had installed loops in other aircraft, with which trials were conducted. Loop bearings taken at night on broadcasting stations in the medium-frequency band showed that the symptoms usually associated with night effect were observed and did not differ in any respect from those observed on similar equipment at ground level. The loop was not recommended as a reliable means of navigation at night except when the stations used were known to be within 50 miles of the aircraft.[4]

Rotating Beacons

The rotating beacon system entailed no transmissions from aircraft, and enabled an aircraft to determine its position without any wireless apparatus except the ordinary W/T receiver and trailing aerial. The observer in the aircraft timed the period between certain known wireless signals by means of a stop-watch, and this period enabled him to determine his bearing from the beacon station. The ground station consisted of a frame aerial rotated by mechanical means with a definite periodicity, usually one complete revolution per minute. The aerial threw a revolving beam of radio waves in exactly the same manner as a lighthouse throws a beam of light waves. A special signal was

[1] A.M. File S.23185. [2] A.M. File 298032/33. [3] A.M. File S.32774.
[4] A.M. File S.34611.

made when the beam was pointing due north, and it was by accurately measuring the time which elapsed from the moment of this signal until the signal strength received in the aircraft died to a minimum that the aircraft navigator was able to determine his bearing from the beacon station. The Germans had employed two stations using this principle on the Schleswig coast for their submarines during the war. Experiments had been begun in the United Kingdom in July 1918. The experimental apparatus was replaced in 1920 by a rotating loop operating on a wavelength of 1,550 metres, and very limited ranges were obtained. The R.A.E. then became responsible for development; a station was erected at Farnborough and preliminary tests took place in September 1923 with a five-foot loop when ranges of 35 miles were obtained.[1] By September 1924, a higher-powered installation had been completed, and R.A.E. tests were successful up to 50 miles range.[2] Early in 1925 Vickers Virginia aircraft of No. 58 Squadron joined in the tests and in July 1925, when the beacon began to transmit on a regular schedule by day and by night, transmissions were observed by aircraft of four squadrons, Nos. 7, 9, 58 and 207.[3] Results were disappointing in the extreme, interference being very bad, ranges poor, and bearings erratic. The use of a wavelength of about 700 metres was decided upon, but ranges were still so disappointing that on 26 February 1926 all aircraft except No. 58 Squadron were taken off the trials and regular transmissions ceased. Carrying on the tests alone, No. 58 Squadron found the new beacon wave of 707 metres fairly free from interference. By July 1927, it was thought that the experimental period of the rotating beacon could be said to be over, and that the time had come to judge its probable utility. Headquarters A.D.G.B. considered that the system had proved sufficiently promising to warrant further trials and to justify alteration of wavelength to one free from interference, and there was general agreement that this was the most efficient and most easily-operated system of D/F for air navigation produced so far, and that it had great advantages over the Bellini-Tosi system in that no transmission by the aircraft was necessary, any number of aircraft could take bearings at the same time, and night error was apparently absent. The erratic results which had at times been obtained were thought to be due to inexperienced operating, and it was undoubtedly true that operators of experience were getting greatly improved results. Later in 1927 the Air Ministry was asked by the Board of Trade to contribute to the cost of erection of a new rotating beacon at Dungeness.[4] An experimental beacon for use with ships had been set up at Gosport in 1924, and in view of its efficiency the Board of Trade wanted to erect another. The Air Ministry had been planning the erection of a new beacon at Martlesham Heath, and the idea of combining with the Board of Trade to share costs seemed sensible. However, the cost of erecting the beacon at Dungeness proved to be prohibitive, and later Orfordness was chosen as the site, since it already had R.A.F. power supplies and communications. Trials were suspended while the new beacon was being built by the R.A.E.

On the basis of experience gained so far, the rotating beacon system was regarded as the panacea for all D/F ills. Wing coils were regarded as being at best a possible stop-gap pending the introduction of further rotating beacons, and it was decided not to fit any more, although aircraft were wired in

[1] A.M. File S.27499. [2] A.M. File 709343/26.

[3] Half-Yearly Report on Signals Work of the R.A.F., 31 December 1925.

[4] A.M. File S.27499.

readiness in case the decision should be reversed. Rotating beacons were also envisaged as the ultimate replacement of the Bellini-Tosi system and as the main source of D/F navigation by day and night.[1] '. . . The special value of the rotating beacon, if the Council's expectations are fulfilled, will be that it will afford a reliable means, at present lacking, of direction-finding during the hours of darkness, and that it will obviate the necessity of carrying complicated instruments in aircraft . . . .' stated an Air Ministry letter to the Treasury in July 1928, the month in which trials of the new beacon began at Farnborough.[2] Treasury agreement for the estimated expenditure involved in the erection of this beacon at Orfordness followed on 7 August, costs being shared by the Air Ministry and the Board of Trade.

The main points disclosed by the early trials at Farnborough were that the new wavelength of 1,040 metres was more satisfactory, ranges up to at least 200 miles being obtained, and that with the increased signal strength it was much easier to train operators. The C.A.S. was satisfied with early progress but was not sure that all units were taking full advantage of the facilities offered. However, operation at Farnborough was only a temporary arrangement, and in February 1929, with trials completed satisfactorily, the beacon was dismantled for subsequent erection at Orfordness.[3] By May 1929, erection had been completed and calibration tests were in progress. An air publication for the guidance of operators using the beacon when it commenced routine transmissions was distributed throughout all bomber units of A.D.G.B., who were to carry out the trials.[4] Special note was to be made of any appearance or evidence of night effect. The beacon began routine transmissions on 20 June 1929.[5] Informed of the opening of the beacon, the C.A.S. stated '. . . This is very interesting and satisfactory . . . . it looks to me as if these beacons will replace the Bellini-Tosi type . . .

In spite of the importance of the trials, reports at first revealed a seeming lack of interest but those made at the end of October showed that bomber squadrons generally had made much more use of the beacon, though there was still far too little information on night effect. An analysis of the returns showed that a high percentage of errors of more than two degrees were due to such factors as inexperience of operators, interference from broadcasting stations, and difficulty with the type of stop-watch in use. Errors by the operating crews were undoubtedly responsible for many inaccuracies, and better results were confidently expected with more practice and the introduction of an improved type of stop-watch. The reports showed that presence of night effect was characterised by flat and displaced minima, and that the limit of effective range appeared to be about 150 miles.[7] However, just as the value of the rotating beacon system seemed likely to be assured, the Air Ministry became concerned about its possible use by an enemy. Ways and means of restricting use by an enemy were suggested, but it was admitted that it would not be impossible for skilled enemy operators to use the beacons on occasions, although the R.A.E. was of the opinion that it would be quite possible to ensure comparative secrecy in time of war.[8]

[1] A.M. File S.23185. [2] A.M. File 779442/27. [3] A.M. File 863874/28.
[4] A.P.38—'Position and Direction-Finding by means of Wireless Transmission'.
[5] A.M. File 863874/28. [6] A.M. File 779442/27. [7] A.M. File 863874/28.
[8] A.M. File S.27499.

By the end of 1929, the Air Staff was anxious to reach a decision on future D/F policy. H.F. D/F equipment was being developed at the R.A.E. but the question was whether the rotating beacon or the Bellini-Tosi method should be the future system of direction-finding, or whether it was still necessary to continue developing them both. Circumstances in the Royal Air Force from 1919 to 1929 were not comparable with later periods. The R.A.F. had suffered drastic cuts following the First World War, and money was not available for ambitious development schemes, either of aircraft or ancillary equipment. The same aircraft receiver, the Tf, was still in general use, and since it was mostly installed in the same aircraft types, or anyway in aircraft of similar performance and range, no doubt it was adequate for W/T communication, but all tests with new ground-to-air wireless apparatus had to be measured against the known limitations of the aircraft receiver. Also, there was not the stimulus of the threat of war, and officially there was no apparent enemy. Experiment and development therefore tended to follow their own course, and not a course dictated by war strategy, geography, or operational necessity. Consequently, it is not perhaps surprising that the same equipment was in use in 1929 as in 1919; that development of the rotating beacon had taken seven years to reach the stage of regular routine transmissions and a further four and a half years to undergo any kind of extended trial; and that the question of its being of more use to enemy than friendly aircraft had not apparently been raised in the Air Ministry until eleven years after the beacon's conception.

In December 1929, a memorandum on position-finding by wireless was prepared for the Air Staff by the Signals Staff. It showed that direction-finding by rotating beacon had many disadvantages, and the tenor of the memorandum strongly favoured adoption of an improved Bellini-Tosi method.[1] Although the right conclusion had been drawn, unfortunately some of the reasons for it were misconceived, and advocates of the rotating beacon seized on them to discredit the premises and prolong the period of indecision. The Signals Staff was certainly over-optimistic in predictions about cathode-ray direction finding, but its faith in the Adcock aerial was later justified. Briefly, it was contended that, so far from being free from night error as claimed, the rotating beacon was very definitely liable to it, if only to an extent; that night error could be almost completely eliminated in the Bellini-Tosi system by substitution of Adcock aerials for the existing aerials; that the risk of aircraft being located through transmitting requests for D/F assistance would be greatly reduced by the shorter transmission period required with the new cathode-ray oscillograph; that rotating beacons might be of more use to enemy aircraft than to our own; that it was easier for D/F ground stations to locate an aircraft position accurately than for aircrew personnel to do so by means of rotating beacons; that it was an easier matter for an enemy to jam beacon transmissions than a D/F ground system; and that it was essential for aircraft taking bearings on rotating beacons to break off listening-out watch on the traffic wavelength whilst doing so.[2] The A.O.C.-in-C., A.D.G.B. commented on the memorandum in detail but his main point was that it was highly dangerous to attempt to settle future policy on assumptions regarding equipment which had not been tried out in the Service and which had not, in fact, emerged from the laboratory stage of development. Although in April 1930 the Signals Staff reported that

[1] A.M. File S.27499.

[2] A.M. File S.27499.

the problem of night effect on medium wavelengths used by D/F ground stations had been solved, the Chief of the Air Staff ruled in May that development of both systems was to be continued, and Air Staff hopes were pinned on the eventual success of the rotating beacon. In order that the rotating beacon system might be fully tested a second beacon was required so that fixes could be obtained, and a suggestion that the experimental beacon at Farnborough should be operated, to save the expense of erecting another beacon pending the results of further trials, was accepted. The beacon began to operate in November 1930. Improvement in the accuracy of bearings obtained by crews during 1930 was noted with satisfaction by the Air Ministry. Night effect, while present, seemed to be negligible.[1]

The future of the Orfordness beacon was considered by the Wireless Direction-Finding Committee at the Board of Trade on 24 January 1930, where it was recommended that the beacon should continue to operate until 31 March 1931, when the position would be reviewed. In August of the same year, the C.A.S. ruled that the beacon would almost certainly be required by the R.A.F. for a further three to five years as a means of developing the rotating beacon method, and by April 1932 the Air Ministry was satisfied that the beacon would be required to remain in operation as an essential adjunct to the Home Defence force, at any rate for several years. However, the General Lighthouse Authorities, with whom the Board of Trade was sharing the expense of running the beacon, were not prepared to state that they could continue contributing after 31 March 1933. Shipping representatives had already expressed a preference for the fixed type of radio beacon.[2] Finally, the General Lighthouse Fund made a reduced contribution as from 1 April 1933. Previously, in May 1931, the Air Ministry had again posed the question of the security of rotating beacons and trials took place in August of that year, three aircraft representing our own bombers being in possession of full particulars of certain changes to be made in beacon characteristics, while three other aircraft represented the enemy and had no prior knowledge of the changes, being informed of them by an 'enemy' ground W/T organisation. Technical opinion after the exercise was that changes could be made to rotating beacons which would render them of little value to enemy aircraft in time of war, but the Air Staff, as well as the commands concerned, thought the results were inconclusive. The unselective Tf receiver was still being used and undoubtedly hampered the trials, and the C.A.S. ruled that trials should recommence when the replacement receiver was available.[3] This decision was again in line with the policy that until new W/T apparatus had been produced, no definite decision about the tactical use and employment of wireless in aircraft could be made. The Air Staff view of the various forms of radio aids to navigation at that time was succinctly stated on 31 October 1931. '. . . One of the principal uncertainties regarding wireless lies in the form of D/F to be adopted finally. There are three types:— Rotating Beacon, Adcock (improved Bellini-Tosi), and Wing Coils. The rotating beacon would be the most promising if (a) it had the range, and (b) the enemy could be prevented from using it; because any number of aircraft can use it at the same time and any aircraft receiver can use it. . . . '[4]

Navigation by means of the two rotating beacons at Orfordness and Cove (Farnborough) was still attempted, but in the years that followed, even when

[1] A.M. File 863874/28. [2] A.M. File 957803/29. [3] A.M. File S.27499.
[4] A.M. File S.27499.

the new aircraft receiver was used, many limitations were disclosed. The main difficulties to be contended with were atmospherics, jamming, and general inaccuracy at medium and long ranges, and it was argued that, if jamming by other stations assumed serious proportions during peacetime, it would probably be easy for an enemy to effect even greater interference during war. It was also pointed out that in practice flights the W/T operator was not disturbed by any consideration such as listening out for operational signals or looking out for hostile aircraft.[1] The Farnborough beacon was moved to Tangmere in 1932/33 so as not to interfere with other experimental and development work at the R.A.E.

The final word on rotating beacons was not spoken until 16 October 1934, when, at the first annual D/F conference, it was agreed that, in spite of certain great advantages, the beacon had such grave operational disadvantages that its development would be discontinued and finance and training efforts concentrated on other methods.[2] Although by this time the R.A.E. was developing a rotating loop for use in aircraft, development of which had lain dormant with the failure of the Vickers Vimy installation, no new factor had come to light which could be said to turn the Air Staff against the rotating beacon method. D/F on high frequency and cathode-ray D/F were still unproved, and the introduction of new and reliable W/T apparatus had not been made on any scale. There was, then, no reason why the decision to abandon the rotating beacon method should not have been taken years earlier, and certainly it could well have been made on the strength of the Signals Staff memorandum of December 1929, with a saving of nearly five years' work.

Direction-Finding Ground Stations

A proposal to build two D/F ground stations, one at Eastchurch and one at Worthy Down, was agreed in March 1924; the Worthy Down station was transferred to Andover early in 1927.[3] At first the time taken by the stations to provide bearings caused concern. In April 1925 No. 58 Squadron was detailed to drop its rotating beacon trials whilst it concentrated for one month on working with the two Bellini-Tosi stations in an effort to speed up operating procedure.[4] All aircraft equipped with W/T made use of the ground stations but little was known at the Air Ministry of the results obtained until in the latter half of 1927 a comprehensive report was compiled by Headquarters A.D.G.B. which summarised the results of two months concentrated wireless duties undertaken by No. 100 Squadron in April and May. W/T communication had been good and the bearings obtained from Andover and Eastchurch had been satisfactory during daylight hours within the area in which a reasonable cut could be provided; at night they were unreliable. By that time both Headquarters A.D.G.B. and Headquarters Coastal Area were pressing for extended D/F coverage: the former wanted a temporary station to be erected for trials at Bircham Newton to replace eventually the station at Eastchurch, which was subject to site error; the latter wanted a station at Cattewater in view of the increased employment of flying-boats and seaplanes

[1] Report by Air Pilotage School on use of W/T D/F in a Home Defence War, August 1933. (A.M. File S.27499.)

[2] A.M. File S.34418.

[3] Half-Yearly Report on Signals Work of the R.A.F., 30 June 1927.

[4] A.M. File 709343/26.

in that area.[1] As a result the D.C.A.S. reviewed the experience gained in the two and a half years during which the stations had been working '. . . Up to the present all D/F training had been carried out on the Bellini-Tosi send-receive method and the results have been very satisfactory during daylight; night results cannot at present be relied upon. The rotating beacon at Farnborough has not so far produced very good results and it is doubtful whether a D/F service on this method will be established for the next two or three years. . . .'[2] Acting on this basis he supported the erection of a station for Coastal Area and agreed that tests should be made of the suitability of Bircham Newton. Two new D/F stations at Mount Batten (Cattewater) and Bircham Newton were completed and in operation in 1928 by which time the Eastchurch station had been dismantled; in the event of war the existing civil stations at Croydon, Pulham and Lympne were to be taken over.[3]

On 5 March 1929 Headquarters Coastal Area requested the provision of another D/F station in the west in view of the increasing use of the Irish Sea and its approaches on exercises and navigation flights. Four days later, Headquarters Wessex Bombing Area made a similar request, but in this instance the need for a fourth D/F station arose from the positioning of the other three, which were all on practically the same base-line. The Air Ministry at first proposed to open a new station at Sealand, and this met with the concurrence of both headquarters. The equipment formerly at Eastchurch was available and could be transferred to Sealand, but it was feared that if the erection of a Bellini-Tosi station at Sealand were authorised, the rotating beacon installed at Orfordness would have completed its trials by the time the new station was in operation, and it was thought probable that the rotating beacon system would render Bellini-Tosi obsolete. The C.A.S. agreed that the matter should be shelved until the end of the year, whilst a careful watch on the Orfordness trials was to be maintained.

A demonstration of direction-finding by means of a cathode-ray oscillograph was given by the Radio Research Board on 15 January 1930. As a demonstration of a scientific principle developed to a practical form the results obtained were satisfactory, but it was quite clear that further research was required before equipment could be produced which would attain the standard of robustness, simplicity and reliability sought by the Service.[4] However, the Radio Research Board was asked to prepare equipment for subsequent experimental use at the R.A.E. Features which the Air Ministry required to be incorporated included a frequency range of 200 to 400 kilocycles per second and an accuracy of plus or minus one degree, with sufficient sensitivity to enable signals to be received from aircraft transmitters, using 0·25 kilowatts, at ranges up to 300 miles. Selectivity and simplicity of operation were also needed. In 1933 equipment employing the cathode-ray method in conjunction with Bellini-Tosi reached the stage of preliminary pre-Service trials at the R.A.E. Research at that establishment into the possibilities of short-wave direction-finding was continually shelved because of shortage of facilities and staff but by 1932 determined efforts had been made and two short-wave direction-finders capable of operation in the 3,000 to 7,500 kilocycles per second band had been constructed. The

[1] A.M. File 745533/27.

[3] A.M. File S.23366.

[2] Half-Yearly Report on Signals Work of the R.A.F., 31 December 1928, and A.M. File S.23366.

[4] A.M. File 963920/29.

R.A.E. equipment was given Service trials at Hornchurch and Biggin Hill, and early results were satisfactory.[1]

The trials were continued in 1933 and 1934, although they were held up in 1934 while the development of special receivers was completed by the R.A.E.[2] Although results continued to be satisfactory, insufficient data was available to enable definite conclusions to be drawn. Belief in the efficacy of the Bellini-Tosi ground station system was fostered early in 1930 when the airship R.100, during the course of endurance trials, cruised for seventeen hours in cloud, effectively checking position by D/F. British civil aviation had always found the system to be adequate but the navigation problems of the R.A.F. were thought to be different, civil aircraft being mainly concerned with navigating on regular services between well-known points, whilst Service aircraft were required to operate across unfamiliar country and over large expanses of sea. However, the use of Bellini-Tosi stations was continued by all types of bomber aircraft, and in 1932 the station at Andover was converted to Marconi-Adcock. Development of Adcock D/F stations had been slow, mainly because of the very poor ranges obtained with aircraft. This failing was apparent in the Andover installation until the R.A.E. suggested a method of improving signal pick-up which subsequently became universal in all Adcock stations. It was at once found that Adcock D/F was considerably more accurate; the improvement was maintained and one year later pilots were showing increasing confidence in the system. The possibility of being able to control aircraft tracks by some method of radio direction-finding was first considered in 1933 at a time when the risk of collision between aircraft flying on converging courses in cloud was causing much concern. Models of a visual azimuth indicator were expected to be ready for Service trials in mid-1934, and it was hoped that the equipment would provide an effective warning system. In 1935 it was found that it did not meet the requirement, and an alternative suggestion that a ground W/T organisation should be devised to keep track of the position and height of aircraft so that they might be ground-controlled was put forward; the scheme was the precursor of subsequent ground control systems.[3]

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[1] Half-Yearly Report on Signals Work of the R.A.F., 30 September 1932.
[2] Half-Yearly Report on Signals Work of the R.A.F., 31 March 1934.
[3] A.M. File 149335/31.

CHAPTER 20

WIRELESS DIRECTION-FINDING, 1934–1939

Although the period 1919–1934 was dominated by the attempt to meet an operational requirement by development of the rotating beacon, and was inevitably a period of frustration, it had been possible to investigate other systems, and the design of equipment, both ground and aircraft, was sufficiently well-founded to enable rapid progress to be made in the next five years. In June 1934 Air Marshal R. Brooke-Popham, Commander-in-Chief, Air Defence of Great Britain, stated that the time had come for a critical survey of existing radio navigational systems to be made in relation to the probable requirements of the next five years. '. . . Progress towards longer aircraft ranges and flying under much more unfavourable weather conditions than formerly has outstripped the existing organisation of wireless direction-finding services . . .'[1]

The R.A.E. had been instructed by the Air Ministry, in 1929, to investigate the possibility of using H.F. D/F for aircraft navigation, particularly in relation to fighter aircraft. R.A.E. work on H.F. D/F development was initiated by testing an experimental H.F. rotating Adcock equipment which had been developed by the Royal Navy. This, however, was found to be unsuitable because its effective range when used with fighter aircraft was about five miles only. The R.A.E. had therefore further developed the Adcock system to increase its range potential; this involved an entirely new design. The major advance made was the conception of using large capacity aerials so that the aerial current was larger and built up a larger voltage across the inevitably large capacity of the shielded leads. Circuit development was undertaken to fit in with this conception and, as a result, not only was a direction-finding system for fighter aircraft successfully evolved, but the Adcock system was also improved. The original method of using vertical aerials with screened horizontal leads for direction-finding, introduced by Adcock during the First World War, had not been used for working with aircraft because of the very short ranges obtained; for this reason the first Marconi-Adcock system installed at Andover had been of limited value. The experience gained by the R.A.E. during the development of H.F. D/F aerials resulted in action being taken to change the aerial system of the Andover M.F. D/F station so that aerial capacity, and consequently effective ranges when working with aircraft, was considerably increased. Thus accurate wireless direction-finding, by day and by night, had been made possible by 1931.[2]

A precise statement of Air Staff policy was made shortly before the first annual conference on direction-finding and radio beacons was held at the Air Ministry on 16 October 1934. It was considered essential that the wireless D/F system should reveal neither the position of outward-bound bomber aircraft nor the fact that they were outward-bound. The transmission of any form of wireless D/F signal by bombers on the outward journey was to be restricted to aircraft which were completely lost. Transmissions were permissible, both from

[1] A.M. File S.34418.   [2] Narrator's interview with Group Captain C. K. Chandler.

aircraft and ground stations, during the return to base. The ground organisation was therefore to be capable of controlling numbers of aircraft, singly or in formation, and of directing them when thick cloud was prevalent to the vicinity of their airfields by night and by day. There was to be no restriction on transmissions by fighter aircraft and ground stations working with them, if the procedure adopted was proof against use by enemy bombers as an aid to navigation. A direction-finding system, organised on a mobile basis and complying with the general requirements for bomber and fighter aircraft, would be required at the outbreak of war to work with a force estimated at twenty bomber and five fighter squadrons. In a Home Defence war, the W/T requirements of Coastal Area would be subordinated to those of A.D.G.B., but in a war in which there was a serious threat to merchant shipping operations of Coastal Area would be given a high priority, and D/F was expected to be of great value to aircraft undertaking long patrols in poor visibility out of sight of land. D/F coverage would then be required for :—

(*a*) The approaches to the English Channel and the southern approaches to the Irish Sea.

(*b*) The southern part of the North Sea.

(*c*) The northern approaches to the Clyde and the Irish Sea.

The main conclusions reached at the conference were that the Royal Air Force should concentrate on the provision of Adcock D/F ground stations and rotating loop aircraft installations; a bold decision in view of the cautious policy followed during the previous six years. In July 1933 preliminary trials to ascertain the possibilities of taking bearings on high-frequency aircraft transmissions had been started with ground equipment developed by the R.A.E.; all previous direction-finding had been carried out on medium frequencies. The conference decided that further trials were to be held, using an A.D.G.B. fighter aircraft working with the Radio Research Board high and intermediate-frequency Adcock station at Slough. The changeover of all R.A.F. Adcock D/F stations to high-frequency, and the linking up of groups of D/F stations by landline, was envisaged. The question of liaison with Civil Aviation was discussed, and it was agreed that Civil Aviation should continue to use existing methods, R.A.F. and Civil Aviation D/F developing independently according to requirements during peace, with sufficient co-ordination to ensure immediate co-operation when needed.

The existing home R.A.F. D/F organisation was one Adcock station at Andover and three Bellini-Tosi stations at Mount Batten, Bircham Newton and the Scilly Isles, all operating on a frequency of 340 kilocycles per second. The conference recommended the following additions and changes, to be in working order by 1938 and fully operative by 1941 :—

(*a*) *A.D.G.B.*

One Adcock station at Leuchars (part use of the R.R.B. Adcock Station at Leuchars had already been arranged); one Adcock station at Sealand; the conversion of Bircham Newton from Bellini-Tosi to Adcock.

(*b*) *Coastal Area*

Conversion of the Bellini-Tosi station on the Scilly Isles to Adcock; the existing Bellini-Tosi at Mount Batten to be abolished and replaced by an Adcock at Prawle Point; the installation of a new Adcock station further east, probably on the Isle of Wight. It was also thought that Coastal Area might be able to share the use of Bircham Newton, Andover, Sealand, and Leuchars. In addition, certain Bellini-Tosi civil aviation stations, which might subsequently be converted to Adcock, could be used by either A.D.G.B. or Coastal Area on request to the Air Ministry.

(c) *Expeditionary Force and Air Striking Force*

The requirement was provisionally estimated as nine mobile stations, but further consideration was thought to be necessary. Other points agreed by the conference included the provision of six H.F. Adcock equipments for Service trials (three in A.D.G.B., two in Coastal Area, and one at Waddington); further research into and development of D/F aids, including particularly cathode-ray D/F; the sending of a representative of the staff of the Director of Scientific Research to the U.S.A. to study development there; the provision of three pilot-operated R/T installations in No. 24 (Communication) Squadron for working civil and R.A.F. stations on medium-frequency; the provision of six rotating loops for trials in Coastal Area aircraft, and two loops each for Coastal and A.D.G.B. for trials on the ground. A direction-finding conference to review progress and development was in future to be held annually. The Chief of the Air Staff agreed to the proposals but brought forward the date by which the expansion of D/F services was to be completed to 1 April 1939.

High-Frequency Direction-Finding

H.F. D/F trials, undertaken by the Radio Research Board Adcock station at Slough, in conjunction with fighter aircraft of A.D.G.B., in late 1934 and early 1935, confirmed the results obtained with the R.A.E. H.F. D/F equipment at Biggin Hill and Hornchurch. Satisfactory bearings could be taken on fighter aircraft at R/T ranges up to the accepted limits of efficient R/T working, about 70 miles at 10,000 feet.[1] In addition, a pilot could, with very little practice, navigate on bearings given him by D/F, and maintain a position above a given point.[2] Provision of a D/F organisation was discussed at a conference held at Headquarters Fighting Area in October 1935. It was expected that fighters might often be called upon to operate out of sight of ground even though over their sectors, and also to operate over the sea when intercepting or when chasing an enemy. In either instance D/F would be necessary, to keep aircraft in the area in which they might be expected to meet the enemy, or to bring them back to their sectors or airfields after a chase. Headquarters Fighting Area therefore defined the requirement as :—

(a) Two or more groups of H.F. Adcock stations sited on the coast, to give bearings and fixes to aircraft over the sea.

(b) An H.F. Adcock station at each sector headquarters to deal with aircraft on patrol out of sight of ground, and to bring back lost aircraft to their sectors or home stations.

(c) A homing system to enable aircraft to reach their bases in bad visibility.

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[1] A.M. File S.34768.

[2] An automatic switching device to switch fighter aircraft R/T installations from 'receive' to 'transmit' periodically for H.F. D/F purposes was developed. This was the forerunner of Pipsqueak, details of which are given in Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

The second annual direction-finding conference, held in November 1935, confirmed the general policy of concentration on rotatable coil installations for aircraft and Adcock ground stations.[1] Indeed, it was considered that the target date for completion of the new D/F system, 1 April 1939, precluded any major alteration in policy, though there was room for minor modification and experiment, mainly with approach and landing systems, and the radio compass. The six H.F. stations ordered as a result of the first conference had been delivered during the year. One had been erected at Waddington and was about to be brought into operation; at Duxford and North Weald instructions had been given for installation to await site testing by a Marconi engineer; and the three remaining equipments, for the Scillies, Prawle Point, and Northolt, had been sent to the R.A.E., where collapsible huts and aerials for them were under construction. Service trials with D/F loops had been satisfactory, and the trials carried out with I.F. and H.F. Adcock stations had shown that although satisfactory results could be obtained from up to 100 miles and from 200 miles upwards, bearings were liable to be inaccurate between about 100 to 200 miles. The main point at issue, however, was the provision of a network of H.F. D/F stations.[2] Under the new expansion announced by the Government in May 1935, the question arose how many stations would be required by bomber, fighter and coastal aircraft.

The requirements of fighter aircraft, and for what afterwards became Fighter Command, were assessed as one D/F station at each sector airfield (Biggin Hill, Catterick, Church Fenton, Digby, Duxford, Hornchurch, Kenley, North Weald, Tangmere and Wittering), one D/F station at Usworth, and one at each of five training stations; sixteen stations in all. By November 1936, considerable use had been made of the H.F. D/F stations in the new Fighter Command and their possibilities had been carefully studied. It was found that ranges of 70 miles were possible with fighter aircraft fitted with the TR.9 installation if the aircraft flew at a suitable height.[3] The average accuracy obtained was two to three degrees, which was enough for homing, for ordinary navigation, and for keeping aircraft within their sectors. However, a much higher degree of accuracy was required to enable fighters to intercept, and further research work was put in hand. One cathode-ray direction finder had been in use in Fighter Command at Northolt for six months, and had given great satisfaction. Orders had been placed for eight sets of this type, four from each of two manufacturers, in order that manufacturing and supply problems might be investigated and to provide models for Service trials; they were expected to be available in about March 1937.

Fighter Command policy was to establish a D/F organisation and to train personnel in the use of the Marconi-Adcock radio goniometer H.F. D/F equipment as a temporary measure until sufficient cathode-ray sets were available.

[1] A.M. File S.34418.

[2] A.M. File S.34418. The problem of manning had also to be solved. The R.A.F. was already well under strength in signals personnel, and with the new H.F. D/F requirement an additional 70 N.C.Os. and 280 operators were needed. Training presented a further problem. The conclusion reached at the Electrical and Wireless School was that while direction-finding principles could be taught at the school, practice in D/F operating would extend the syllabus unduly, besides raising difficult questions of signals organisation, and would be costly in aircraft and apparatus. It was therefore decided to transfer trained operators at units to D/F work and replace them on point-to-point work by trainees from the school.

[3] A.M. File S.37600.

At that time it was thought that the cathode-ray method would replace the goniometer method within two or three years. The equipment would be installed at all stations not provided with cathode-ray equipment, and general installation was expected to begin early in 1937. The system would consist of Marconi-Adcock aerials and radio-goniometers coupled to the R.1084 receiver. A standard station consisted of a wooden D/F hut measuring ten feet by ten, and an additional hut containing a rest room and battery-charging room, in which was also housed the flasher for obstruction lights if they were fitted. The plan was that when cathode-ray apparatus was eventually fitted the second hut would contain a standby motor generator plant for use in the event of a power supply failure. The D/F station would be electrically heated, and would be connected by control cable to the station operations room. At first the D/F stations worked on the operational frequency, but when the TR.9 was modified a separate D/F frequency was established. Following the No. 11 (Fighter) Group exercises of 1936, it became apparent to the Director of Signals that at least two D/F stations per sector would be needed, and he continually pressed for their provision until the principle was finally agreed by the Chief of the Air Staff on 2 December 1937.[1]

Concurrently with other exercises and trials, the Biggin Hill experiments were conducted in 1936, and although they were primarily concerned with the interception problem, H.F. D/F as the latest method of assisting fighter navigation played an important part in them.[2] Three D/F stations, at Biggin Hill, North Weald, and Northolt, undertook the positioning and homing of the fighter aircraft, and M.F. D/F stations at Bircham Newton and Andover provided fixes for the 'hostile' bomber aircraft. However, the distances involved were too great for accurate fixing on either high or medium-frequencies, and, in view of the low power of the TR. 9 aircraft installation, it was clear that H.F. D/F stations should be sited close to the area where navigation assistance was required. Support for the contention that one station per sector was insufficient was provided on 31 March 1937 by the A.O.C.-in-C., Fighter Command, who outlined his probable future requirements as three per sector, one at sector headquarters, and the other two about half-way between sector headquarters and the coast in each instance. Two additional H.F. D/F stations were provided in the Biggin Hill sector two months later, and in August the A.O.C.-in-C. confirmed his estimate of the requirement. Then began the selection of sites, applications for the lease of land, requests for financial approval, and the purchase of additional D/F equipment, delivery of which was not expected before 1939.

By the end of 1937, five sectors, Biggin Hill, North Weald, Hornchurch, Northolt and Duxford, had been equipped with three H.F. D/F stations each. They were of the goniometer type, Marconi DFG. 12.[3] A second fighter group, No. 12, had been formed in April 1937, and to equip all sectors in both groups required a further 14 sets of D/F equipment. Further expansion subsequently

[1] In spite of the success achieved with H.F. D/F the R.A.E. had little faith in the system and advised against its adoption. No alternative scheme was offered, however, and the Director of Signals decided to disregard this advice and to urge forward completion of an H.F. D/F system, especially for Fighter Command.

[2] *See* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception', for further details.

[3] Trials of cathode-ray equipment were still in progress.

increased this requirement to a total of 29 sets, but no contract was placed at once, as it was hoped that tests with cathode-ray equipment would be successful and enable that type to be ordered. This was the very kind of hiatus that planning at the annual D/F conference had been designed to avoid. The delay lasted until 30 March 1938, when it was pointed out that the cathode-ray trials were still inconclusive, and the purchase of goniometer equipment was urged.[1] Provision could be made for subsequent fitting of cathode-ray apparatus, if it finally proved satisfactory, without alteration to the existing aerial system or feeder lines. Purchase of the goniometer equipment was approved one week later, on 7 April 1938. There was also some delay in the provision of the forward R/T relay stations, only five of the projected 29 being connected by mid-1939. By that time, 9 only of the 18 fighter sectors had a D/F fixing service in operation. A spurt in the speed of installation of H.F. D/F stations and forward relay R/T stations was made in July 1939, but on 22 August there were still four sectors which could not hope to be completed before mid-September 1939.

At first, pilots tended not to take proper advantage of the new D/F facilities. In February 1939 all Fighter Command units were adjured to make full use of the new stations, and constant practice in obtaining homing bearings as a matter of routine, and routine testing of R/T equipment immediately after take-off, were ordered.[2] By the time of the Home Defence Exercise in August 1939 pilots had largely overcome their initial apathy, and it was clear that a great improvement had been made since the air exercises of the previous year.

Under the expansion schemes, the question arose how many H.F. D/F stations would be required to provide a service for Bomber Command aircraft. The Air Staff laid down that there was no necessity to direct an aircraft all the way in to its own airfield; it would be sufficient to fix the position of aircraft within five miles of its airfield, and from there the pilot would have to find his own way in.[3] The use of D/F in blind flying conditions was not at that time visualised. The D/F system for bombers was also to be capable of providing fixes and bearings for aircraft returning from raids while they were in the skip area of local stations situated in eastern England, and of guiding them until they were within range of the local stations. This ruling postulated the erection of long-range D/F stations with radio transmitters of higher power in central or western districts.[4] Bomber airfields were organised in well-defined groups of from four to six stations each, with two or more squadrons at each station. Therefore although the Air Staff stated that the aim was continuity of attack rather than density, it was thought that any one group of stations might have to deal with ten returning aircraft in a 15-minute period. Such a rate demanded some system of traffic control by ground D/F stations.

The D/F conference of 1935 had provided for a total of 37 H.F. D/F stations for Bomber Command, on the basis of one per station. This was obviously the ideal, but it was subsequently considered that it would be too expensive in equipment and personnel, and Headquarters Bomber Command was informed

[1] A.M. File S.39190. [2] A.M. File C.11533/42. [3] A.M. File S.38130.

[4] Due to the limitations imposed on H.F. D/F by the 'skip area' phenomena, the same D/F station could not fulfil the two functions of (a) giving positions to aircraft returning from raids at 200 miles distance, and (b) homing. It was therefore necessary to install a number of long-range stations on the western side of England.

on 31 October 1936 that requirements would be met by a total of 27 stations, allocated to give the five bomber areas, Boscombe Down, Bicester, East Anglia, Lincolnshire and Yorkshire, short and long-range cover at the rate of two short and two long-range stations per area, except that East Anglia would have an extra pair of short-range stations owing to the greater concentration of airfields there.[1] The remaining five stations were allocated to isolated training units not situated within any particular area. The stations were located to give, as far as possible, a real homing service to the aircraft based at each airfield as well as a positioning service to aircraft seeking neighbouring airfields.[2] The short-range stations were equipped with Marconi DFG. 12 aerials, feeders and goniometers, and the R. 1084. D/F stations working together were connected by landline, and the short-range stations were provided with both R/T and W/T facilities.[3]

Headquarters Bomber Command continued to urge the provision of one D/F station per airfield. It was argued that, in practice, pilots and navigators had so little experience, especially of high-speed aircraft, that a fix was of little use to them since they must work forward in each case from the line of the fix to obtain their true position. In conditions of stress and difficulty, it was unlikely that they would have the confidence and calmness of judgment, engendered by experience, to do this. In fact, aircraft of Bomber Command could be regarded as being in the same position as those of Fighter Command, where it was accepted that the pilot could not navigate and that homing D/F stations must be provided at every airfield. A scheme for the provision of one D/F station per airfield was finally approved by the Chief of the Air Staff on 11 April 1938. Headquarters Bomber Command had also asked for a Regional Control service at a number of selected airfields, which would provide :—

(*a*) H.F. D/F.

(*b*) *Lorenz* blind landing.

(*c*) Short-range R/T control.

(*d*) Full night-flying lighting.

(*e*) Modern fog-lighting.

(*f*) Regional weather broadcasts.

(*g*) W/T guard on S.O.S. wavelength.

(*h*) A Duty Control staff with a Regional Control officer always on duty to assist aircraft in difficulties.

Nine Regional Control stations were provided, at Leuchars, Linton-on-Ouse, Waddington, Wyton, Abingdon, Boscombe Down, Mildenhall, Manston, and near Sealand, and in May 1939 approval was given to the provision of a second H.F. D/F station at each.[4]

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[1] A.M. Files S.38120 and S.34418. The stations were to be situated at Benson, Boscombe Down, Abingdon, Cranfield, Watton, Wattisham, West Raynham, Honington, Grantham, Finningley, Leconfield, Driffield, Abbotsinch, Turnhouse, Aldergrove, Castle Bromwich, and Speke, plus ten long-range stations, three pairs of which were to cover the Belgium and Holland approach lanes and two pairs the approach from north Germany.

[2] A.M. File S.37600.

[3] In 1938 it was decided that all bomber aircraft should be fitted with W/T equipment, the only reservation being that light-bomber squadrons were limited to three per squadron until they were rearmed. The previous policy had provided for W/T installations for all night bombers but for only three aircraft per day squadron. The new policy meant one W/T operator per aircraft, and entry and training programmes for the signals trades were revised in order to cope with the new demand. (A.M. File S.23185, Part II).

[4] A.M. File S.38120.

By November 1938, progress in the erection of a total of 29 long and short-range stations for Bomber Command was as follows:—

(a) *Erected*—Mildenhall, Abingdon, Boscombe Down, Cranfield, Honington, Finningley, Leconfield and Grantham.

(b) *Erection anticipated complete in December*—Waddington, Linton-on-Ouse, Wyton.

(c) *Under erection*—Marham, Feltwell, Upwood, Watton and Wattisham.

(d) *To be erected*—Benson, West Raynham, Dishforth, Driffield, Hemswell, Scampton, Bassingbourn, Bicester, Stradishall, Harwell, Hucknall, Cottesmore and Upper Heyford.

Erection of the outstanding D/F stations did not proceed altogether smoothly, and arrangements were made for two Marconi engineers to tour the outstanding stations and to give advice to contractors and A.M.W.D. engineers.[1] The need for rigid discipline and constant expert supervision in this type of work was obvious.

When the original allocation of H.F. D/F stations was made in November 1935, Coastal Command was provided for on the basis of one station at each airfield or base.[2] Later, for reasons of economy, the allocation was reduced, but Headquarters Coastal Command joined with Headquarters Bomber Command in fighting the reduction.[3] The station erected in 1936 in the Scilly Isles gave useful service to Coastal Command aircraft pending the introduction of the full H.F. D/F service. Then, in 1936, it was hoped that cathode-ray apparatus would be ready in time for other installations.[4] Later, when it became obvious that development of the cathode-ray equipment was indefinitely delayed, installation of the goniometer type was proceeded with, and in April 1939 the Coastal Command H.F. D/F organisation comprised Pembroke Dock, Felixstowe, Dyce, Thorney Island, Thornaby, Leuchars, Catfoss, Manston, Bircham Newton, Wick and Detling.[5]

A programme for the erection of a total of 62 H.F. D/F stations for operational use, plus a further 20 for marginal and training purposes, was included in the Air Estimates for 1936/37, but as early as the first few months of 1936 it was apparent that constant pressure would have to be brought to bear if the target date of 1 April 1939, set by the Chief of the Air Staff, was to be achieved. Further, if the D/F organisation was to be fully operative by April 1939, it was desirable that the majority of stations should be working not later than April 1938 to give aircrew and ground operators the necessary experience. Contracts for equipment were placed at once, but in view of the many urgent commitments in the Service and in industry it was not to be expected that any appreciable delivery would be forthcoming within twelve months. Also, sites required careful selection, land had to be purchased or leased, and personnel and works services had to be provided. By 26 March 1938, a total of 33 sites for D/F stations had been found. The average time taken from first inspection to access was six months, most of this time being taken up in negotiations. Further planned expansion meant that another 45 sites were wanted, and at this stage the Air Ministry arranged for two technical officers to be permanently employed in selecting sites.

[1] A.M. File S.38120. [2] A.M. File S.34418. [3] A.M. File S.38120.
[4] A.M. File S.37600. [5] A.M. File S.38120.

It was regarded as essential for an officer of the Lands Branch to accompany each technical officer to open negotiations, but experience had shown that the Lands Branch was often hampered and prevented from closing a deal on a lease for a D/F site quickly because the price asked was a few pounds higher than seemed justified; the ensuing bargaining took months, and in the meantime the whole D/F organisation was held up. The Lands Branch was therefore asked to make available two officers armed with such freedom of action that they could close a reasonable bargain on the spot without subsequent criticism.[1] The Director of Works contended that the most fruitful causes of delay were the demands peculiar to D/F siting and the restrictions they imposed on the surrounding land, involving not only the lease of two or three acres for the site but also the restriction of cultivation of some fifty acres of adjoining land, coupled with continually changing Signals requirements. The Signals Staff agreed to modify the restrictive demands if one week's notice could be given of the proposed use of such machinery as tractors in the vicinity of sites. The Lands Branch was already fully occupied in acquiring land for operational airfields, training establishments, satellite airfields, and radar sites, as well as D/F and *Lorenz* sites, and the Director of Works was consequently unable to release two officers as requested. He tried without success to obtain extra staff, and the position on 16 September 1938 was that negotiations involving 18 sites passed to the directorate earlier in the year were still outstanding, while delivery of four sets of D/F equipment was expected by 23 September and a further ten sets one week later, making fourteen awaiting sites. Further sets were likely to accumulate in the weeks that followed because, as a result of pressure from the Chief of the Air Staff, the firm of Marconi was proposing to work 24 hours a day and at week-ends. A progress report made by the A.M.W.D. at the time gave some indication of the difficulties. Among their many obstructions were tenants' resistance, protracted negotiations with owners, acquirement of the sanction of county councils, and sometimes the abandonment of sites for technical reasons. In February 1939, authority was obtained to employ outside Lands agents, and the rate of acquisition then began to improve considerably.[2] Acceleration of the rate of erection after sites had been acquired was also necessary, and the Air Staff was in exactly the same position as the A.M.W.D. had been; technical officers could not be spared to supervise the work. Instead, arrangements were made for two Marconi engineers to tour sites individually, advising contractors, dealing with difficulties, making recommendations, and reporting briefly to the Air Ministry on progress.[3]

Use of H.F. D/F for Blind Approach

Two early systems for making a blind approach to an airfield in bad weather, the QGH and ZZ systems, made use of two-way ground-to-air communication. In each the ground and air operators followed a set procedure at the end of which pilots of aircraft were generally in visual contact. QGH was simply a descent-through-cloud procedure, and ZZ landings were not normally attempted unless visibility exceeded 1,000 yards. In the ZZ procedure, the aircraft called the airfield D/F station and was given courses to steer which brought it over the airfield at a stated height, generally 2,000 feet. The aircraft was then

[1] A.M. File S.34418. [2] A.M. File S.34418.

[3] Sites outstanding in mid-June 1939 were:—*Lorenz* Beacons 78, V.H.F. D/F 37, Cathode-Ray D/F 16 and H.F. D/F 9. (A.M. File S.34418).

instructed by the ground station to fly away from the airfield on a given course, letting down at a given rate per minute. The aircraft continued to transmit its call-sign at intervals, and eventually it was given a reciprocal course to steer. While it turned on to this course the operator transmitted the word 'turning'. The let-down then continued, given heights being reached at given distances from the start of the runway. The aircraft continued to make transmissions and the ground operator gave the course corrections. In the hands of experienced operators the system was good, and it was used up to the end of the war at airfields which had no beam approach system. However, the approximate safe limitations of such a system were a cloud base of about 600 feet and visibility of about 800 yards, and it was realised some years before the war that an improved system was needed. The probable R.A.F. requirements and the necessity for co-ordinating R.A.F. and civil aviation methods were discussed at the first annual D/F conference in 1934, and during 1936, trials were made of the *Lorenz* and Hegenberger systems, as a result of which Standard Beam Approach was eventually introduced into the R.A.F. Meanwhile, ZZ procedure remained the only blind approach system in use, and it was decided that new H.F. D/F stations were to be sited, in relation to the airfields they served, so that ZZ approaches were facilitated. In order to use them for this purpose, it was desirable to site a station in a direct line with the runway. Two H.F. D/F stations, at Aldergrove and Mildenhall, were erected on this basis and were used successfully for ZZ approaches, but subsequently, when other sites were being selected, the strongest opposition to their erection in the best approach lanes was forthcoming from station commanders, whose attitude was supported to some extent by Headquarters Bomber Command.[1] The policy was therefore changed and endeavours were made to site D/F stations so that they offered as little obstruction as possible while being close enough to the airfield to offer ZZ facilities.

Aircraft Direction-Finding Loops

Development of D/F loop installations in aircraft had been started during the First World War, and was one of the methods of D/F navigation considered at the time of the statement of policy on the use of radio communication by Home Defence bombing squadrons at the end of 1923. But at this time the loop was very much out of favour. It was too unwieldy for inclusion in any but the largest aircraft, and even in those its installation was impracticable. So for ten years from 1924 to 1934 little research or development was undertaken in this form of D/F in the United Kingdom. Undoubtedly the potential value of the rotating loop as an aircraft installation had been obscured in the fifteen years following the war by the obsession with the rotating beacon on the ground. The operational requirement was a direction-finding system which was independent of transmission by aircraft. There were three systems to choose from; the rotating beacon, the rotating loop, and the fixed wing coil. Early experience led the Air Staff to believe that the rotating beacon was in every way superior to the other two, and in fact the limitations of the fixed wing coil were obvious. So it was not until it was becoming obvious in 1933 that the rotating beacon did not adequately meet the requirement that an alternative system was sought. As a result of the trials made of the rotating loop system in 1934, the first annual D/F conference decided it was to be one of the two major forms of wireless direction-finding used in the R.A.F.

[1] A.M. File S.38120.

After the rotating loop trials had been in progress for about one year Headquarters Coastal Area was unable to provide much further data, but considered that the system was sound and constituted the best all-round method so far tried in aircraft, and its installation in all flying-boats was recommended.[1] The A.O.C. Wessex Bombing Area also thought that the degree of accuracy obtained with the rotating loop was most satisfactory when it was remembered that the wireless operators carrying out the trials had had no previous experience in direction-finding by wireless. At the second annual D/F conference in November 1935, Headquarters Coastal Area and Headquarters A.D.G.B. recommended that the rotatable loop be standardised for all appropriate types of aircraft, and provision for a total of 1,074 loops was made in the Air Estimates for 1936. However, with the advent of high speed aircraft, designers were concerned at the drag to be expected from external loop installations, and development of retractable loops was begun.[2] On 25 June 1936 the Aircraft Equipment Committee recommended the introduction of non-retractable loops for Vildebeeste, Singapore III, Scapa, Valentia, London, Stranraer and Hendon aircraft, and trials of retractable installations in Harrow, Whitley, Battle, Blenheim, Anson and Wellesley aircraft.[3] Six firms undertook the design of retractable loops, with the assistance of the R.A.E., but an inspection of the designs aroused some apprehension in 1937 because of the danger of the loop icing up.[4] Meanwhile, in November 1936 the policy of fitting loop aerials in aircraft was confirmed.[5] By that time, retractable rotating loops had already been included as part of the standard equipment on civil aircraft flying the Transatlantic and Empire routes, and they were also being employed to an increasing extent on the European routes.[6] External loops mounted on top of the fuselage were fitted in five Whitley and five Harrow squadrons in 1938, and the fitting of other squadrons followed.[7]

Towards the end of 1937, the Air Ministry began to show interest in the possibility of using the D/F loop on high as well as on medium-frequency, for homing at short range to ground stations using the T.1087, with suitable coupling between the loop and the R.1082 in aircraft.[8] Information was required of the ranges at which such homing might be possible, and of whether errors would be so large as to lead aircraft on to a wrong track on first receiving a bearing at say 45 degrees to the axis of the aircraft. Early in 1938 the R.A.E. was asked to carry out tests in the 70 to 100 metre wave-band, to discover at what range polarisation error was negligible and at what range homing was unreliable. It was recognised by the Air Ministry at that stage that even medium-range homing might be of assistance not only to Bomber Command but also to enemy bombers. Tests carried out in a Handley Page troop-carrier aircraft showed that, by day, polarisation error was plus or minus two degrees up to a range of 70 to 75 miles, but that beyond those limits polarisation and fading became appreciable; safe homing was possible up to 100 miles. Generally, results obtained beyond this range were characterised by fading, apparent swinging of bearing, and occasionally by absence of minima. By night, polarisation error was plus or minus two degrees up to 25 miles, and the safe homing range was 45 to 50 miles. Rapid and irregular fading and absence of definite minima were experienced at greater ranges. Signal strengths

[1] A.M. File S.34611. [2] A.M. File S.39974. [3] A.M. File S.34611.
[4] A.M. File S.39974. [5] A.M. File S.39487. [6] A.M. File S.37600.
[7] Bomber Command File BC/S.20758. [8] A.M. File S.43388.

were still good above 300 miles, but fading and absence of minima prevented bearings being taken. The R.A.E. drew attention to the well-known vagaries of H.F. propagation phenomena, and emphasised the danger of attempting to draw general conclusions regarding H.F. propagation from a limited number of observations.

In June 1938 further tests were proposed to ascertain to what extent ranges were affected when the ground transmitter was of high power, such as those at Ongar and Rugby, and what quadrantal error was obtained. However, the R.A.E. considered that the previous tests had shown conclusively that the limit of satisfactory homing range was not due to any limitation of power at the transmitter, and there was no reason to expect that an increase in transmitter power would result in an increase in satisfactory homing range; the limiting factor was the presence of a reflected ray producing fading, change of bearing, and flat minima. The quadrantal error had been measured on 3,500 kilocycles per second and was found to be 8 degrees. At the time the R.A.E. was planning to investigate the properties of an opposed-loop homing system for its freedom from night errors; it was intended that further tests on the single-loop homing system should be merged with experiments on the opposed-loop system, so that a direct comparison of the two methods could be made.[1] Experimental work was continued for a number of years, but was finally shelved in April 1941 in view of the impending trials of Gee, and, to a lesser extent, because of the projected introduction in operational aircraft of navigator-operated loop receivers.

Trials were carried out as early as 1935 to test the value of B.B.C. transmitters for direction-finding purposes; the results showed that bearings could be obtained although they might be unreliable over large areas.[2] Before the war began preparations were completed for denying to the enemy their assistance to navigation in the form of M.F. beacons.[3] Arrangements were made for the synchronisation of a number of transmissions of each B.B.C. programme, so dispersed as to make it impossible for the *Luftwaffe* to use them in conjunction with aircraft D/F loops. The Air Staff policy then was that no beacons would be made available in the United Kingdom, in view of their possible use by enemy aircraft. This was a defensive policy in keeping with the state of preparedness of the country, but it severely restricted the value to the R.A.F. of aircraft loops, both for training in peacetime and for operations in war. The loop might be useful as a check on D.R. navigation during long operational flights if suitable enemy or neutral beacons or broadcasting stations could be found for the purpose, but it could not be used for homing unless there were beacons in the United Kingdom. However, great difficulty in navigation on long operational flights was not anticipated; there was general confidence in the standards of D.R. navigation, and it was not until after the war began, when the many difficulties and hazards came to be fully appreciated, that provision of a system of home-based navigation beacons was decided upon. Indeed, the Air Ministry announced in March 1939 that even D/F ground stations would only be brought into use in extreme emergency, and it was considered that conditions would never be such that a D/F station would be busy with many aircraft at one time. The need for the operation of a continuous navigational

[1] A.M. File S.43388. [2] A.M. File S.35602.

[3] *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures'.

service was not envisaged.[1] Anxiety was also felt about the threat of enemy use of the transmissions of H.F. D/F stations for loop D/F, and the problem of spoiling aerials at ground stations so that homing would not be possible except at very short ranges. Further tests were therefore carried out in November 1938 on two Daventry short-wave transmissions, which showed that if an aircraft flew in the approximate direction of the beam, the error of 90 degrees expected on horizontally-polarised beam transmitters was consistent and could be taken into account; it was, therefore, not an error at all when the operator was aware that a station was emitting horizontal polarisation. Further research on this problem was continued after the outbreak of war.

In July 1939 it was suggested that, in time of war, a certain number of transmitting stations, both enemy and neutral, could be exploited for navigation purposes if aircraft navigators and wireless operators were trained to make the best use of any Intelligence that could be provided. Arrangements were made for the collection and dissemination of such Intelligence, but it was not until after the outbreak of war, on 17 January 1940, that a beacon for training purposes began transmissions from Andover.[2]

Medium-Frequency Direction-Finding

By the middle of 1937 the recommendations made in 1934 regarding the provision of M.F. D/F stations had been carried into effect with certain minor changes, and there was in force a medium-frequency D/F safety service. It comprised Adcock stations at Andover, Bircham Newton, Leuchars and Sealand, operating on 340 kilocycles per second; Adcock stations at Mount Batten, Tangmere and on the Scillies, operating on 285 kilocycles per second; and Bellini-Tosi stations at Bircham Newton and Manston operating on 370 kilocycles per second. The stations were connected by a landline system designed for the speedy passing of bearings from one to the other without the use of W/T.

In 1938, the policy for the wartime absorption into the Service of the civil aviation M.F. D/F organisation was formulated together with instructions for bringing it into force. The main objects were to give Coastal Command a D/F service for the use of G.R. squadrons working over the sea, to provide an alternative service for Bomber Command aircraft in difficulties, and to contribute towards the scheme for identification of friendly aircraft in conjunction with R.D.F. The civil network covered the whole of the British Isles, but since most of the stations were Bellini-Tosi, a separate reduced organisation using the Marconi-Adcock civil stations was necessary for operation at night. Meanwhile, under the threat of war, the changeover of civil stations which were to be re-equipped with Marconi-Adcock under the Maybury scheme was speeded up, the R.A.F. being particularly concerned since Bomber Command aircraft were expected to require D/F assistance mostly at night.[3] Nevertheless, the service was to be used in emergency only, since the position of civil stations was well known to the enemy, and it was thought that continuous transmission would enable enemy aircraft to make use of them as radio beacons. Arrangements were made for manning the stations on the outbreak of war, the plan being to retain civilian operators where possible, and sealed instructions were issued to them, to be opened on the declaration of an emergency. In each instance the nearest R.A.F. unit was detailed to act as 'parent' station.

[1] A.M. File S.49652. [2] A.M. File S.1620. [3] A.M. File S.45387.

Use of M.F. D/F for Identification

There were two major problems of identification to be solved. One was the separation of friendly from enemy aircraft on radar screens; the other was the necessity to ensure that enemy aircraft could not make use of D/F ground stations simply by imitating call-signs. The first problem was much the more serious, and it began to give concern to Headquarters Bomber and Fighter Commands in 1936.[1] An exercise was held on 1 July 1937 with the object of ascertaining the capacity of a pair of D/F stations to fix the position of bomber aircraft approaching the coast, the fixes obtained being telephoned to the Fighter Command Operations Room immediately they were determined.[2] The stations employed were Andover and Bircham Newton, the line joining the two being assumed to be a coastline which was being approached by returning bombers. A total of 64 transmissions was made from the air at the rate of one per minute; a fix was successfully obtained by the two stations during each transmission, and the degree of accuracy was acceptable. As a result of the trials, it was suggested that a number of medium-frequency D/F stations, including some of the civil stations, should be use as the basis of an identification organisation, Bomber Command homing needs being met by its H.F. D/F system and possibly by a beacon system. A proposed layout and bracketing of stations was put forward, having the capacity to deal with the expected number of returning aircraft.[3]

In October 1937 possible methods of providing warning or of routeing returning bombers through certain defined lanes were discussed. The possibility of using set routes and corridors was dismissed as it was thought that the required degree of accuracy in navigation could not be expected from aircraft returning from long operational flights, and a system of challenge and reply by W/T was decided upon, the reply to include aircraft position, height, course and speed, and an identification number. The system suffered from the same basic defect as the corridor system; aircraft navigators could not be expected to give all the required information with any certainty of accuracy at all times. The method was tested in December and proved to be altogether too cumbersome. A revised method was introduced in which positions of returning bombers were fixed by a ground organisation which reported direct to Headquarters Fighter Command. The bomber was not challenged, but made a simple identification signal. In essence this was the same system as that tried out in the first exercise in July 1937. During the Home Defence exercises of August 1938 the new identification procedure was used, but the exercises showed that the only real solution was automatic identification on the screens of the radar reporting system.[4] A method of distinguishing friendly from enemy aircraft on radar screens during the process of detection and location was already being developed at Bawdsey, but no final solution was in sight.[5] Meanwhile, the exercises confirmed that the best interim course was to make use of the M.F. D/F system, and this method, known as the Voluntary Identification Method, in which the operator transmitted automatically when the navigator calculated the aircraft was 100 miles from the English coast, was in force at the outbreak of war.[6]

A requirement also existed for a system whereby D/F ground stations could identify aircraft calling for assistance, and thus prevent help being given to

[1] A.M. File S.39973.

[2] *See also* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

[3] A.M. File S.40818.

[4] A.M. File S.40818.

[5] A.M. File S.39973.

[6] A.M. File S.40818.

enemy aircraft. A method had been used in Home Defence exercises in which a serial number transmitted after the aircraft call-sign acted as identification.[1] This system, involving the use of what was known as a Movement Serial Indicator, was introduced in 1939, in spite of objections from Headquarters Coastal Command, who thought it would complicate the task of the aircraft wireless operator, increase the time taken to obtain navigational aid, and reduce the number of aircraft which could obtain assistance. Headquarters Coastal Command also considered that the risk of the enemy making use of D/F stations located in the United Kingdom was small and could be accepted. However, the Air Ministry view was that confusion should not arise, as an aircraft worked only one pair of D/F stations, and then only in emergency; once again it was clearly stated that transmission for D/F purposes between air and ground would take place only in conditions of absolute emergency.[2]

Cathode-Ray Direction-Finding

The visual cathode-ray direction-finding method held a number of advantages over the aural radio-goniometer method, and when it was decided to include the development of a cathode-ray oscillograph, with Adcock aerials, and with aural reception incorporated as part of the circuit, in the 1930/1931 development programme, high hopes were entertained that this type of equipment would eventually replace the aural method.[3] Development was continued at the R.A.E. until 1935, when an installation was made available for Service trials in Fighter Command. It was brought into operation at Northolt early in 1936, and was then probably the only one of its kind in existence, certainly in the United Kingdom. The equipment worked fairly well, and a review of the year's work put before the third annual D/F conference stated that it had given great satisfaction; but in actual fact the tests revealed a number of faults. However, the A.O.C.-in-C., A.D.G.B., on 5 February 1936, stated that sufficient data had been collected to justify the adoption of the cathode-ray system for all direction-finding in the Service.[4] The Air Ministry, acting on recommendations made by the annual development programme conference on 24 February 1936, ruled in March 1936 that specifications should be produced by the R.A.E. in collaboration with the R.R.B.; trials were to be completed as soon as possible, and if results were satisfactory, the cathode-ray system was to replace the goniometer system.[5] On 30 March, when the co-ordination of D/F and R.D.F. and allied problems was discussed, a change of policy in provision of the aural to the visual direction-finder was recommended.[6] The Air Ministry decided however, that specifications and drawings for the aural type should be completed, and that it was impracticable to adopt the visual type until the planned Service trials had been completed.

In May 1936, the R.A.E. produced specifications for both the Service trials' cathode-ray equipment and the production Marconi goniometer equipment, DFG. 12 with R.1084.[7] Development contracts for four sets of cathode-ray equipment were placed with the firms of Plessey in September 1936 and Marconi in October 1936.[8] Nearly three years after the specifications had been completed,

[1] A.M. File S.49652.
[2] A.M. File S.49652.
[3] Cathode-ray D/F enabled bearings to be taken on transmissions of extremely short duration. When reception conditions were bad it was possible for comparatively inexperienced operators to obtain reasonably accurate bearings quickly. (A.M. File S.46122).
[4] A.M. File S.35037.
[5] A.M. Files S.37600 and 471526/35.
[6] A.M. File S.38091.
[7] A.M. File 471526/35.
[8] A.M. File S.38091.

in 1939, the four Marconi DFG. 16 sets were installed at Leconfield, Honington, Pembroke Dock and Biggin Hill, and the four Plessey DF. 14 R sets at Kenley, Leuchars, Hornchurch and Aldergrove. Completed reports on Service trials of the equipment had been received from all eight stations by the outbreak of war, and with minor recommendations all the reports were favourable. Equipping of the new H.F. D/F stations had been held up for a time in the hope that the cathode-ray equipment would be ready to replace the aural goniometer equipment. Eventually it was decided to go ahead with the installation of the aural-type equipment, but installations were completed in such a way that the aural equipment could be replaced by visual cathode-ray equipment without difficulty. Even so, the H.F. D/F programme lagged behind schedule, and was still incomplete on the outbreak of war, when it was too late to introduce the cathode-ray equipment on any wide scale.

Direction-Finding in Overseas Commands

The first direction-finding station to be erected by the R.A.F. for the use of aircraft was installed at Ta Silch, Malta, and was in operation by January 1924. By then a station had been built at Abu Seuir and a location for a second station in Egypt was being sought, while in Iraq equipment for two stations had been supplied but had not been installed. Two Bellini-Tosi stations began working at Mosul and Ramadi in 1925, but their use was discontinued, and it was not until 1930 that a regular D/F service was supplied by the erection of two Bellini-Tosi stations at Shaibah and Hinaidi. The Iraqi Government provided a civil D/F station at Rutbah in 1932, a second at Baghdad in 1933, and a third at Basrah in 1935. The R.A.F. stations at Shaibah and Hinaidi were converted to Adcock in 1933, and in 1934 one of the Bellini-Tosi equipments thus released was erected at Mosul. Improvised forms of D/F were in use in Iraq well before 1930. In 1929 a locally made D/F set was used for training purposes, and practice in the use of portable frame aerials for direction-finding was carried out by all aircraft and armoured car units. Exercises took place in which aircraft equipped with frame aerials were required to locate a supposed force-landed aircraft. A system was developed which met with much success and was instrumental in locating an aircraft which actually had been obliged to land in the desert at night.

In 1929 there was a revival of interest in wing coils, several squadrons in Iraq using them in conjunction with the Tf receiver. Then, in response to a request from No. 205 Squadron, Singapore, two sets of wing coils were prepared at the R.A.E. for installation in Southampton flying-boats. These were fitted at Singapore early in 1932, and after a few months of trials the squadron reported on the layout and asked for modifications. However, the need for a full D/F service at Singapore remained, and in 1933 it was decided to open an Adcock station for the use of R.A.F. and civil aircraft. Delivery of the equipment took place in 1934.

In consequence of the expiration on 1 October 1932 of the agreement with Persia for the use of Persian territory by Imperial Airways aircraft *en route* to India, an alternative route along the Arabian coast with aerodromes at Bahrein and Sharjah was established.[1] D/F equipments were installed at Sharjah in 1933 and at Bahrein in 1934.[2] The Government of South Africa began to install

[1] Half-Yearly Report on Signals Work of the R.A.F., 31 March 1933.

[2] A.M. File 262955/33.

Bellini-Tosi D/F stations in 1932, and by 1933 a triangle of stations was in operation at Germiston, Victoria West and Capetown. In 1934 the provision of a further ten wireless stations, to include D/F facilities operating on the Adcock principle, was planned, so that at any point on the air routes two or three stations would be available for cross bearings.

In 1934, civil D/F stations were installed at Cairo (Almaza) and Alexandria, and in 1935 at Brindisi and Mersa Matruh on the India route. Generally speaking, the policy was to transfer the responsibility for handling air transport traffic to administrations over whose territory the air routes passed.[1] Arrangements of this kind had been made in Iraq, Egypt and the Sudan, the Sudan Government having installed a chain of D/F stations from north to south by 1937. Stations were also built on the route to West Africa from Khartoum, while the Nigerian government erected stations at Kano and Lagos; communication with these stations was effected on H.F. and direction-finding on M.F. In India, too, a network of civil M.F. D/F stations was built along the trans-India route and also on the west coast at Bombay and on the east coast at various points and as far south as Madras. The trans-India network was continued through Burma to Rangoon and further south to Tavoy and Victoria Point; not all the stations were regarded as reliable for direction-finding. In the Far East civil M.F. stations were built at Singapore, Penang and Hong Kong. The 1936 direction-finding conference recommended the installation of an M.F. station at Kuching and H.F. stations at Rangoon, Singapore, Kuching and Hong Kong.[2]

Although the overseas air routes were fairly well provided with M.F. D/F stations, the policy of allowing them to become the responsibility of the local government as civil stations meant that the R.A.F. had few D/F facilities under its own control for its own use. Obviously such a situation might be expected to right itself to some extent on the outbreak of war, when air traffic would mainly assume a military nature and the R.A.F. could expect to receive the priority accorded in peacetime to civil aviation. There was, however, clearly a requirement for an increase in D/F coverage and particularly for the introduction overseas of H.F. D/F, experiments with which had been begun abroad in 1934. Results indicated that installation of H.F. equipment would be of great advantage at nodal points on the air routes, especially in areas where atmospheric interference was high, such as the Persian Gulf and Malaya.[3] It was therefore decided in July 1938 to provide an additional six M.F. D/F and 10 H.F. D/F stations.[4] The M.F. stations were to be located at Singapore, Kuching (Sarawak), Kuantan (Malaya), Aqir (Palestine), Aden and Ceylon, and the H.F. stations at Singapore, Kuching, Jesselton (British North Borneo), Sungei Patani (Malaya), Egypt (two), Nairobi, Aden, Rangoon and Ceylon. However, it was not found possible to send H.F. equipment abroad before the war, and in the ensuing months many changes were made to the plan. But it formed the basis of provision of direction-finding equipment overseas during the early war years.

[1] In 1938 a great increase in the density of civil air traffic in Egypt made it necessary for the civil aviation authorities to restrict R.A.F. use of their direction-finding stations to the use of a Marconi DFG. 11 portable Bellini-Tosi installation at Heliopolis. DFG. 11 equipment was also installed at Amman, Transjordan, in December 1938.

[2] A.M. File S.37600. The plan to provide H.F. D/F at Hong Kong was not implemented as it was considered that the civil M.F. station fulfilled the direction-finding requirement.

[3] Half-Yearly Report on Signals Work of the R.A.F., 31 March 1934.

[4] A.M. File S.45161.

CHAPTER 21

WIRELESS DIRECTION-FINDING IN HOME COMMANDS 1939–1945

Because the M.F. D/F organisation, including that taken over from civil aviation, was largely required as an identification system, and was in any event of no use to Fighter Command, and since security considerations had prevented the establishment of a wireless beacon system, the only wireless navigation system available to all commands in 1939 was H.F. D/F. The planned H.F. D/F installation programme had suffered many delays, and had not been completed.

Research on and development of H.F. D/F had been continually shelved until 1930 because the rotating beacon had absorbed so much of the R.A.E. research potential. Then, following the decision made in November 1935 to equip all Fighter Command sector airfields and all Bomber Command and Coastal Command bases with H.F. D/F stations, several setbacks occurred. The principle that at least two stations were required at every Fighter Command sector was not finally approved until December 1937, over one year after the exercises of 1936 had shown such provision to be necessary. The original decision to provide every Bomber Command airfield with one H.F. D/F station was changed in October 1936, as the project was considered to be too expensive in equipment and personnel, and the policy was not reintroduced until April 1938. In addition, although the original intention had been to establish the D/F organisation and to train personnel with radio-goniometer equipment installed in such a way that it could readily be replaced by cathode-ray equipment if Service trials were satisfactory, a stage was reached in 1937 when contract action for the provision of radio-goniometer equipment to meet requirements was postponed in anticipation of the successful production of cathode-ray equipment. This resulted in a delay of one year before the purchase of the required equipment was approved. Then followed the series of delays in the siting and erection of the various stations, and by September 1939 four fighter sectors still awaited completion of their H.F. fixer organisation. In Bomber Command too, several stations awaited completion of H.F. D/F facilities, and continual expansion of the programme meant that there was always an installation back-log. One result was that pilots and crews were not sufficiently accustomed to the use of D/F facilities to have the confidence which they afterwards gained.

However, there had been no H.F. D/F service of any kind before 1936, yet by 1939 it had become the only sure radio aid to navigation, apart from the M.F. D/F identification and safety service, for all R.A.F. commands. It was providing the only means of blind-approach landings, and it had become a vital link in the Fighter Command system for the air defence of Britain. There had been some delay through an over-optimistic appreciation of the development state of the cathode-ray system, but it was natural that there should be resistance to the spending of much effort and money on a system believed to be outmoded. Altogether from 1934 to 1939 the right balance between vigorous planning and caution in introducing improved equipment was preserved.

General Survey of D/F Systems

From the outbreak of war it was found that aircraft crews had the utmost difficulty in navigating successfully on long trips over enemy territory and over the sea.[1] The basis of all air navigation was dead-reckoning, but the difficulty of forecasting wind velocities accurately over long distances resulted in large errors in D.R. positions.[2] For aircraft of Bomber Command there were no radio aids to navigation deep in enemy territory except possibly enemy and neutral beacons. In emergency, radio silence could be broken and assistance of the allotted M.F. D/F section requested, but the chances of getting an accurate fix at long range were poor. When returning to base, bomber aircraft could use the station H.F. D/F frequency for homing when within 100 miles, but there were no M.F. beacons, all B.B.C. transmitters had been synchronised and spoiled, and the M.F. D/F service, although available in emergency, had another important function entirely unconnected with assistance to aircraft, that of identifying returning aircraft and fixing their position for the benefit of the Fighter Command defence system. Thus it was that bomber crews had the utmost difficulty in finding their targets and in returning to base.

D/F was never regarded as a method of navigation; the only recognised method of navigating an aircraft was D.R.[3] There were three other means by which the position of aircraft could be determined, map-reading, radio position-finding, and astro-navigation, but all were subject to certain natural limitations. The three main limiting factors in radio position-finding were enemy interference, distance from the source of transmission, and technical failure, and the early aids dependent upon wireless transmission were particularly susceptible to these factors.

Complete confidence was placed in dead-reckoning navigation, and navigation was never carried out solely by radio. Radio operators were carried in case of emergency and because it was convenient to combine their rôle with that of air gunner; their status in the early days of the war was not in any way comparable with that of other aircrew. The importance of radio was recognised by the Air Staff, who had laid down in 1936 that all bomber and similar aircraft should be equipped with it, but there were a number of factors which militated against full appreciation of radio as a navigational aid. The equipment in use in aircraft left much to be desired, both in performance and reliability.[4] The standard of operating was low.[5] Bearings from D/F ground stations varied in accuracy.[6] There were no M.F. beacons available in Britain or France.[7] The strict W/T silence that was imposed for security reasons tended to mask the value of radio. There was a general lack of confidence in radio in all its aspects, and while bearings given by ground stations and bearings taken in the air with

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[1] A.M. File S.40818. [2] Radio and Air Navigation Committee—Paper No. 5.
[3] Radio and Air Navigation Committee—Paper No. 3.
[4] A.H.B./IIE/75A. 'War in the Ether.' [6] Coastal Command File CC/S.9119/1.
[5] Bomber Command File BC/S.20489, Part II. [7] A.M. File S.2712.

the D/F loop were regarded as a useful check, a bearing which disagreed with the dead-reckoning position was likely to be discarded as useless.[1] This underlined the need for wireless operators to be in continual contact with the ground; a navigator was likely to place more reliance on a series of bearings from trusted stations than on an isolated fix from a remote one, and an operator who was in continual contact with the ground was far more likely to be able to anticipate a navigator's needs. However, in the early stages of the war, with W/T silence the rule, an operator could not always feel complete confidence in his ability to get the right kind of D/F assistance just when it was wanted; still less could he inspire such confidence. Again, in many of the early aircraft the operator had to man a gun during long periods, generally during just those periods when navigational assistance was most needed. An attempt was made to overcome the second difficulty by providing a D/F loop to be operated by the navigator, but no real answer was found until the increased size of aircraft allowed the carrying of a crew-member whose sole duty was to operate the wireless equipment.

A memorandum on the use of D/F as an aid to navigation was issued to bomber squadrons by Headquarters Bomber Command on 24 March 1940.[2] The highest importance was attached to crews reading and absorbing the information contained in it, the gist of which was that, while successful air navigation was based on dead-reckoning, accurate navigation over long distances could not be maintained by D.R. alone owing to the inability of meteorologists to forecast wind velocities accurately over wide areas. On the other hand, none of the methods used to assist dead-reckoning was sufficient in itself to conduct the navigation of aircraft in all circumstances; D.R. navigation therefore remained of paramount importance. The errors likely to be encountered when using D/F were particularly stressed, and indeed attempts by operators to obtain, for instance, H.F. D/F homing at distances far greater than 100 miles showed that the limitations of the particular forms of D/F were not as widely known as they should have been. The difficulty at that stage, that is, the stage at which pilots and crews had completed their training and probably several operational sorties, was to remind them of the limitations and inherent inaccuracies of D/F without undermining their confidence in it. This the memorandum endeavoured to do.

The most important period for D/F as an aid to navigation may be said to be from the winter of 1940/41, when aircraft began to operate in increasing numbers, to the middle of 1942, when the advent of radar aids greatly reduced the need for D/F. At the start of the war, the D/F organisation was well able to cope with the scale of operational flying possible at that time, but as the commands expanded, parallel expansion of the D/F services brought many problems, and the production of new equipment at times lagged behind the operational requirement.[3] Every Bomber Command base had its own H.F.

[1] Courts of enquiry investigating flying accidents not attributable to enemy action often found that pilots preferred to attempt to fly below cloud and rely on visual contact navigation than fly above cloud and make use of aids to navigation. The overall percentage of accidents involving errors in navigation and misuse of radio aids for the period 1940/1943 was slightly over 7. Within the period, percentages varied. From mid-1942 until the end of 1943 the figure was just under 4 per cent, the reduction being directly attributable to the introduction of Gee; it is evident therefore that from 1940 until mid-1942 the percentage was much higher than 7.

[2] Bomber Command File BC/S.20768/88/Sigs. *See* Appendix No. 13.

[3] A.H.B./IIE/75A.

D/F station, eventually most of them had two, and congestion on high frequencies became a serious problem until the introduction of radar aids made homing on H.F. the exception, and allowed the closing of fifty per cent of the stations. Up to April 1941, the M.F. organisation was hampered by its responsibility for the identification procedure, but it reached a peak as a fixing service early in 1942, and continued to be widely used right to the end of the war. The M.F. beacon policy was reversed in 1940, when a system of homing beacons was brought into force, albeit under the overriding control of Headquarters Fighter Command.

Radio ranges, which had been used in the U.S.A. for some years before the war, were subsequently installed in all areas from which U.S.A. aircraft operated, and a number were made available in the United Kingdom and abroad for the use of aircraft of Transport Command. The radio range was a refined form of radio beacon whereby signals were beamed into two or four beams. The beams were orientated so that they pointed in the most useful directions, such as along an approach route normally used or towards another main airfield, and, in some instances, along a main runway for use as an airfield approach aid. The sectors between the beams radiated the letter A or N in morse code, adjacent sectors radiating different letters; the overlap between the two letters formed a steady beam. The pilot of an aircraft flying along one of the beams heard a steady note; when he was flying off the beam to either side he heard either A or N. Signals could be received, on the two or four fixed tracks to which the system was limited, at distances up to 100 miles. Theoretical accuracy of plus or minus one degree was seldom achieved because of ground irregularities near range stations. Development of an omni-directional radio range was in progress by 1945 in both the U.S.A. and the United Kingdom, and an experimental model developed by the R.A.E. had reached flight test stage by the end of the war.

The 'Darky' system, an emergency R/T organisation providing low-power communication, was introduced in March 1941 primarily for the use of Bomber Command aircraft at night, and was intended to supplement the facilities already provided by the D/F and regional control systems. Aircraft and ground stations used TR.9D on a frequency of 6440 kilocycles per second, and the already short range of the equipment was further reduced so that if an aircraft in distress or uncertain of its position over the United Kingdom received an answer to its call, it was able to determine its approximate position by obtaining the identity of the station answering the call. The aircraft could then ask for weather information, and the assistance of searchlights as directional beacons could also be obtained. The facilities provided by the Darky system were later made available to aircraft of Coastal Command.[1] With the development of the balloon barrage as a method of passive defence, and the establishment of such barrages around large towns and at many key points on the east coast, there arose a danger that Allied aircraft might inadvertently fly into them, although their siting was known to all flying units. Balloon sites were therefore equipped with automatic transmitters, known as 'Squeakers', which radiated a characteristic signal on 6440 kilocycles per second when balloons were in position.[2] On reception of the signals aircraft not only received warning of the danger, but in many instances were provided with an approximate check of position.

It was a long time before the production of new aircraft radio equipment allowed the fitting of even a majority of operational aircraft, and the old

[1] Coastal Command File CC/S.7512/7/4.

[2] A.H.B./IIE/76A.

equipment caused many difficulties. Fighter Command fought the Battle of Britain virtually without V.H.F. D/F, and the introduction of this equipment was never fully completed outside Fighter Command. Coastal Command aircraft had great difficulty in meeting convoys, and at a vital phase of the maritime war their ability to home to convoys was restricted by W/T silence. A requirement for homing aircraft to the transmissions of U-boats was never successfully met. The cathode-ray D/F service was a disappointment to Bomber Command, though it later gave good service to Transport and Coastal Commands. The rapid expansion of all commands brought many personnel difficulties, the standard of air operating at one point being dangerously low.

Aircraft Wireless Equipment

At the outbreak of war the standard wireless equipment installed in R.A.F. aircraft was W/T receiver Type R.1082 with transmitter Type T.1083, and the modified version of R/T transmitter/receiver Type TR.9, which was the only wireless equipment available for single-seater aircraft. The R.1082/T.1083 installation was difficult to tune and to operate, the most serious drawback being the necessity to change coils in both transmitter and receiver for most changes of frequency, and particularly when changing over from H.F. to M.F. or vice-versa. No spot-frequency tuning or click-stop device was provided, with the result that much time was usually required to set up the transmitter when frequency was changed. With the natural difficulties inseparable from working in a cramped space, particularly in flying clothing, frequency-setting whilst airborne was poor, and considerable tolerance had to be allowed by ground station operators. Many of the wireless failures and instances of non-compliance with procedure instructions could be traced to inexperience of operators, but their duties were carried out in conditions of great practical difficulty, and only a thoroughly well-trained operator could fulfil all his duties satisfactorily with the equipment at his disposal.

The Directorate of Signals had raised an operational requirement for a replacement for the R.1082/T.1083 installation in 1935/36. Development of a suitable aircraft installation, to enable full use to be easily made of the proposed radio navigational systems and to provide adequate communication channels, was required. However, by the outbreak of war no progress had been made at the R.A.E., so the assistance of the radio industry was sought by the Director of Signals. An installation, eventually known as T.1154/R.1155, was developed with the utmost urgency, in conjunction with the Marconi Company, from existing new Marconi equipment. Authority to introduce T.1154/R.1155 into general Service use was not obtained until a committee set up by the Chief of the Air Staff approved the proposals made by the Director of Signals.

The Marconi installation incorporated a system by which frequencies could be pre-selected, and a special D/F circuit, with visual indication for homing, was included in the receiver. Its operation was simple and straightforward and its performance was much superior to that of R.1082/T.1083. By the end of April 1940, design and layout of the Marconi installation had been completed for five types of aircraft which were to be retrospectively equipped, Wellington, Blenheim, Hampden, Whitley and Hudson.[1] However, the output from production was insufficient to permit more than a protracted retrospective

[1] A.M. File S.49915.

installation programme in addition to installation on aircraft production lines, and T.1154/R.1155 did not begin to reach squadrons until the end of 1940, and then only in limited quantities. It was not until 1943 that the last R.1082/T.1083 was replaced in Coastal Command.

Aircrew Wireless Operators

The expansion programme for 1938/39 included a requirement for 2,500 pilots, 2,069 observers, 3,867 wireless operator/air gunners, and 554 air gunners, to be provided by the recruiting programme. However, changes in the method of recruitment and in the terms of service of non-pilot aircrew had to be made in October 1938 in an attempt to improve the quality of recruits and to speed up recruiting. For some time there had been a growing belief that the existing system of providing observers, wireless operators and air gunners from the tradesman ranks could not be relied upon to produce efficient crew members fully competent to meet any emergency. Experience showed that the effective employment of non-pilot aircrews in their basic trade in addition to their crew duties was impracticable even in peacetime, and in any event it had always been accepted that wartime aircrew employment would be on a full-time basis. It was therefore decided in October 1938 that all wireless operator/air gunners should be drawn from the ranks of the boy-entrant wireless operator, and that they should be employed continuously on aircrew duties after completing crew training. Then, after about three years as wireless operator/air gunners, some 25 per cent of them would be selected for training as observers, and would spend the remainder of their service as such. This was in line with previous policy, as the trade of wireless operator had for long been one of three from which the supply of observers was mainly drawn. The remaining 75 per cent would complete their initial aircrew engagement. Observers were also to be obtained, as a temporary measure, by the direct entry of young men of a high educational standard, but the intention was that eventually all observers should be drawn from wireless operators.[1]

An essential condition of success for the new scheme was that the assumption that observers could be men of a lower standard than pilots should be finally abandoned, and that they should be placed on an equal footing with pilots as regards pay, status, prospects of promotion and commissioning. Had the scheme been fully implemented it would have greatly improved the prospects not only of the observer but also of the wireless operator/air gunner, who could have looked forward to the possibility of eventual commissioning as an observer. But the scheme had one inherent weakness; it was patently uneconomic, at any rate in wartime, to train a man for one task and subsequently transfer him to another. So, although some months after the outbreak of war Air Ministry pressure on the Treasury brought the granting of equal career prospects for pilots and observers, the career prospects of wireless operator/air gunners were not enhanced in any way until later in 1940, when aircrew were automatically given senior N.C.O. status on completion of training. Even then wireless operators were not eligible for time-promotion in the same way as pilots and observers, and their opportunities for commissioning were restricted to a small proportion of air gunner posts which were to be filled by officers in order to attract men of the right type into the category. The posts were fundamentally

[1] A.H.B. Monograph 'Manning Plans and Policy'.

created for gunnery leaders, and normally went to air gunners rather than wireless operator/air gunners; and, in the event, by June 1941 only 2 per cent of airman air gunners had been commissioned.

It was of course natural that there should be a sharp distinction between the rewards offered to the PNB (Pilot, Navigator, Bomb-Aimer) recruit on the one hand and the wireless operator/air gunner recruit on the other. The standard of education necessary for the latter was below that required for the study of navigation; wireless operators received a grounding in the theory of electricity and wireless but they were not signals specialists, and the gunnery course was at first restricted to a few weeks. Qualities of leadership were not likely to be so widely needed in this category as amongst pilots, and a slightly lower physical standard could be accepted. The category of wireless operator/air gunner gave ample opportunity for young men of average fitness and intelligence with a sound but undistinguished educational background to play an active and important part in the air war, and it gave the same opportunity to those who failed as pilots or navigators or were unacceptable for some superficial physical reason. Nevertheless, the gap between the rewards and career prospects of the wireless operator/air gunner and those of his fellow crew members was very wide, and undoubtedly contributed to the low standard of operating which persisted until improvements were made.

Early in 1941, Headquarters Coastal Command drew attention to the increasing occurrence of W/T failures, almost invariably due to bad servicing or to faults which could have been rectified in flight, and ordered that in all instances where negligence or inefficiency was apparent, disciplinary action was to be taken.[1] An analysis of W/T failures, carried out by Headquarters No. 18 Group, revealed that nearly every failure was due to inefficient air operating, and Bomber Command squadron commanders were continually reporting on the low standard of efficiency of operators arriving from operational training units.[2] The general situation was a bad reflection on signals training and policy. The large number of operators who persisted in requesting D/F assistance on group operational frequencies showed that the signals organisation was not properly understood. Congested and unsuitable frequencies were used unnecessarily, and it was evident that signals briefing left much to be desired. Group training flights were eventually formed in Bomber Command, especially designed to improve operators who were below standard, and excellent results were achieved, and remedial measures were instituted generally, but even as late as 1942 the situation was still causing concern. However, during that year the percentage of signals failures dropped steadily, and the general standard of operating was generally improved.

Meanwhile, during 1941, the government of Canada had begun to urge the commissioning of wireless operator/air gunners on the same basis as that employed for pilots and observers, up to 33 per cent of output of training schools and a balance of 50 per cent after operational experience had been gained. The strict limitation of the number of commissions available to wireless operator/air gunners had doubtless assisted in attracting the majority of the best aircrew candidates to training as observers and pilots, and in Canada

[1] Coastal Command File CC/S.9119/1.

[2] Coastal Command File CC/S.9119/1 and No. 3 Group O.R.B., September–December 1941.

it was regarded as essential that greater inducement should be offered to candidates of high quality to enter the wireless operator category. A compromise was reached in July 1941 when it was agreed that commissions should be granted to 10 per cent of output on completion of training and an additional 10 per cent after operational experience. To provide for personnel already trained, retrospective commissioning action was taken with 20 per cent of the total output up to that time less the number already commissioned.[1]

Operating Procedure

In the early days of the war aircraft were deemed to be the responsibility of their parent station from take-off to landing, and operators kept watch on their station H.F. D/F frequency when they were not using M.F. for navigational assistance or for identification.[2] All reporting and control was done on the station H.F. frequency, and the D/F facility enabled aircraft to be homed to base at the end of their flight. When 100 miles from the English coast on the return flight operators changed to M.F., identified, and obtained a fix or bearing if required to do so by the navigator. In practice, due to errors in D.R. navigation, fixes were often requested when aircraft were as much as 400 miles out, and identification was frequently not given until aircraft were in sight of the coast.

By the middle of 1942, when all aircraft had been equipped with I.F.F., and nearly all with Marconi T.1154/R.1155, the whole of the M.F. D/F organisation was used almost exclusively for its intended purpose, a system of M.F. beacons was in operation, the emergency Darky organisation was in being, and group operational frequencies were in use in all groups, the operating procedure had undergone many changes.[3] In the interests of security, and because the increase in the number of operational aircraft meant that the amount of assistance which could be given to each was decreased, as far as possible only radio aids to navigation which did not involve transmissions by aircraft were used, such as beacons and radio track guides. Those systems which involved transmissions by aircraft were used only in emergency. In Bomber Command an M.F. D/F section was allotted to each group and normally received all distress calls, requests for D/F assistance, and identification signals. In an emergency, or when an aircraft was flying in an area for which its own M.F. section was unsuitable, any other appropriate section could be called. It was impressed on operators that bearings were not to be requested from H.F. D/F stations, of which there was one at nearly every Bomber Command airfield, when an aircraft was more than 100 miles distant, as beyond that range lay the skip area, in which the risk of large errors and reversed sense was very great. Wireless operators were to be ready to give the correct verification signal if challenged by a D/F ground station, and to challenge ground stations if their signals were thought to be of doubtful authenticity.[4] When aircraft were over the sea, transmitters were set up on the appropriate M.F. D/F frequency so that no time would be lost if it became necessary to transmit a distress call.

[1] A.M. File S.69366 and A.H.B. Monograph 'Manning Plans and Policy'.

[2] A.H.B./IIE/75A.

[3] *See* Appendix No. 15 for full details of signals procedure in a bomber group.

[4] As verification by use of the code S.D.1082 considerably slowed down the service, ground stations did not challenge an aircraft which used a correct call-sign unless there was good reason to suspect that the call was not genuine.

Whenever possible, aircraft on return flights were to approach the English coast at a height not exceeding 2,000 feet; if I.F.F. was working properly identification procedure could then be dispensed with. If I.F.F. was unserviceable, or if aircraft were not equipped with it, identification signals were to be made when 60 miles from the coast. No signals could be transmitted without the authority of the captain, who was to be kept informed of the station with which the wireless operator was in contact or about to establish contact, and who was to be notified immediately in the event of wireless failure.

The signals organisation and procedure stood the test of the first 'thousand bomber' raid on 30/31 May 1942 remarkably well, but one or two revisions were made before the second similar raid on 25/26 June. Operators were particularly requested to keep traffic down to the minimum essential for safety because of the heavy loading of all D/F sections, and special attention was drawn to the amount of interference liable to be encountered on the M.F. beacon frequencies and to the tendency of the enemy to operate only some of his beacons on any one particular night. A change in the identification system was also made; although all aircraft were expected to approach the English coast on return at a height below 2,000 feet, I.F.F. was to be used, and those returning according to the planned times were not to identify on M.F. because of the congestion that would otherwise result. Aircraft forced to turn back before the target had been reached were, however, to carry out identification procedure if flying below 2,000 feet in order that needless interception might be avoided.

A standard distress procedure was stipulated for aircraft of each individual command. Bomber Command aircraft made distress and other relevant calls on the frequency of the M.F. D/F section allotted to them for the sortie. Coastal Command aircraft made distress calls on the appropriate group operational frequency, and also by R/T on the convoy frequency of 2,410 kilocycles per second if within range of a convoy or shore station. Then, if time permitted, aircraft changed frequency to that of the appropriate M.F. D/F section and repeated the distress signal. Fighter Command aircraft made distress and other relevant calls on R/T. Air/sea rescue aircraft, and other aircraft detailed for air/sea rescue work, listened out on the distress frequency of 500 kilocycles per second, to which dinghy transmitters were set, and also used 385 kilocycles per second for homing purposes, including the homing of marine rescue craft to dinghies after sighting. Marine craft were equipped with R.1082/T.1083 and M.F. loop for homing to search aircraft and dinghies, in addition to R/T. Exercises in air/sea rescue organisation and D/F homing were carried out regularly. The whole organisation for the rescue of aircrew forced down in the sea was dependent upon bearings taken on the transmissions of the aircraft before ditching, or on transmissions from the dinghy radio after ditching. Dinghy radio, however, was not in general use until late in 1942, because of the delays in production experienced after its development early in 1941.[1]

The possibility of altering I.F.F. impulses to indicate on ground radar screens that an aircraft was in distress was considered at an early stage of design, and a system of switching I.F.F. to a different channel so as to widen the generated impulse was incorporated. The effectiveness of this method, which was never more than supplementary to the normal distress procedure, depended to some

[1] *See* A.H.B. Monograph, 'Air/Sea Rescue' (A.P. 3232).

extent on range, but in addition there was always the possibility that disaster would come upon an aircraft so suddenly that there would be no time to send a distress message or S.O.S., although there might be time to switch the I.F.F. from one stud to another. An extension of this method, the use of broad I.F.F. by an orbiting aircraft as a means of homing rescue vessels to dinghies, was given operational trials in 1943, and was introduced in No. 19 Group in August 1943. It had only a limited success, however, due to the fact that there was much spurious broad I.F.F. caused by faulty I.F.F. equipment and negligence in the correct setting of switches. Headquarters A.D.G.B. expressed particular concern that the use of broad I.F.F. for this purpose should not add to the confusion already existing from spurious impulses. By early 1944 marine rescue craft had been fitted with R.1155 and Marconi loop, and marine craft operators had become skilled in the use of D/F equipment and in homing procedure.[1]

H.F. D/F Organisation

When the principle of one H.F. D/F station per Bomber Command airfield was restored in April 1938, the first installation programme was for a total of 29 stations. There were, however, serious delays in the erection of the stations, and in July 1939 many of them were still outstanding. Eleven stations had been completed at Mildenhall, Abingdon, Boscombe Down, Cranfield, Honington, Finningley, Leconfield, Grantham, Waddington, Linton-on-Ouse and Wyton. The position with the outstanding stations improved considerably in the next few weeks, a further ten coming into operation by the outbreak of war.[2] Marham, Harwell, Bassingbourn and Watton opened watch, though on restricted hours only because of personnel difficulties. Upwood, Wattisham and Hemswell, which were in the process of being calibrated, had further calibration waived and came into operation. Feltwell opened a restricted watch, having only one trained D/F operator, and Cottesmore was also on a restricted watch pending the completion of training of Service operators. Benson was ready but was temporarily unserviceable.

At first, Bomber Command stations were ordered to keep continuous watch if the personnel situation allowed, whether aircraft were operating or not, but experience showed that this system was detrimental to efficient watch-keeping, particularly when no calls were received over long periods.[3] The system made heavy demands on the limited numbers of D/F operators available, and imposed an unnecessary strain. After five weeks of continuous operating, Headquarters Bomber Command suggested a system which restricted the hours of watch-keeping, and asked the groups to submit their views.[4] The groups agreed with the suggested revision, and on 20 December 1939 Headquarters Bomber Command proposed that all regional control D/F stations continue to keep a 24-hour watch, that each group maintain one non-regional station on a 24-hour

[1] Coastal Command File CC/S.9110/3/Sigs.

[2] The H.F. D/F requirement for R.A.F. aircraft in France was stated as one station for every two bomber or reconnaissance squadrons, one for each fighter squadron, and one at Nantes. By the end of April 1940 five stations had been completed for the force of ten bomber squadrons, but only three stations were in operation for seven fighter squadrons, no special H.F. D/F service had been provided for the four reconnaissance squadrons, and there was no station at Nantes. However, three stations were in operation for regional control and identification purposes.

[3] A.M. File S.38120.

[4] A.M. File S.20489, Part II.

watch, and that all other stations not engaged with aircraft from their parent station should be prepared to open watch at one hour's notice on request. The system was operated within the command from late December 1939, formal Air Ministry approval being given in February 1940.

Meanwhile, the expansion of Bomber Command continued. In September 1939, notification was given that H.F. D/F would be required at seven more bases, North Luffenham, Syerston, Swinderby, Oakington, Waterbeach, Coningsby, and Middleton-St.-George. By January 1940, 23 Bomber Command H.F. D/F stations were in operation, five of which were regional control stations and a further five of which were keeping watch under the new system.[1] Several more outstanding stations were completed in the early part of 1940. About this time, congestion on H.F. frequencies became a serious problem, and to relieve it a second H.F. D/F station was installed at all the larger bases. In August 1940, provision of a second station at O.T.Us. was also agreed. With further expansion, another 15 bases were being planned and prepared, and sites for H.F. D/F stations were selected and preparatory work begun.[2]

With the approach of the winter of 1940/41, all H.F. D/F stations which were manned with sufficient D/F operators began to keep continuous watch during the hours of darkness, in view of expected aircraft diversions due to winter conditions.[3] If a group cancelled operations, the D/F stations in that group were not closed down without reference to Headquarters Bomber Command, who gave the necessary authority only if aircraft of other groups were not operating. Stations unable to keep continuous watch for personnel reasons were kept ready to open watch immediately on receipt of instructions. Instead of each operational base tending to regard its H.F. D/F station as its own exclusive property, any station could be switched quickly to the assistance of aircraft within its range.[4] Thus each station became part of a flexible organisation which could be used to the best advantage. The new organisation was of particular value in that production facilities for any large increase to meet the requirements of the 1940/41 winter did not exist, and there had been a delay in the production of new D/F equipment. However, it did not alter the primary function of an H.F. D/F station, which remained that of homing aircraft to their base.[5]

On 24 December 1940 Headquarters Bomber Command and Headquarters Coastal Command were informed that, consequent upon the universal adoption of V.H.F. equipment in Fighter Command, a number of D/F stations belonging to No. 11 Group would shortly be relinquished.[6] It was anticipated that the seven stations belonging to Biggin Hill, Hornchurch and Kenley could be given up almost at once, and five belonging to Debden and Tangmere in the near future. Further stations would be available from the Northolt and North Weald sectors but not for some time. Subsequently, stations from Nos. 12 and 13 Groups were added to the list. However, a change in V.H.F. policy delayed the date by which any of the stations could in fact be released.

Headquarters Bomber Command considered that the best use to which the stations could be put would be to link them to the regional control centres with the object of providing an H.F. fixer service for aircraft diverted to these centres.

[1] A.M. File S.20489, Part II.
[2] A.M. File S.38120.
[3] Bomber Command File BC/S.20489, Part II.
[4] No. 7 Group O.R.B., December 1940.
[5] No. 1 Group O.R.B., 1941.
[6] A.M. File CS.8571.

On 15 April 1941, the Air Ministry completed proposals for forming the stations into a regional control fixer service. Headquarters Bomber Command at first agreed, but later, on 22 July 1941, asked that suitable stations should be allocated in pairs to the operational group areas and tied by direct landline to group operations room switchboards. This was agreed and stations were allocated to :—[1]

No. 1 Group	West Lutton, Lutton.
No. 2 Group	Shropham, Steeple.
No. 3 Group	Coltishall, Wix.
No. 4 Group	Loftus, Swanland.
No. 5 Group	Gayton-le-Marsh, Hockwold.
No. 8 Group	Stow Upland, Great Wakering.

Provision was made for the laying of landlines, but owing to further delays in the Fighter Command V.H.F. R/T installation programme, and to a shortage of line plant in the Huntingdon and Brampton area, the approach of winter 1941/42 found Bomber Command still without the new fixer service.

The H.F. Fixer Service finally came into operation in January 1942. The stations were not equipped with transmitters, but were connected by telephone to the group operations switchboard. They were calibrated to all frequencies used by D/F stations in the group so that they could be set up on any one of them accurately and rapidly, and they were manned throughout the progress of operations. Requests for fixes were telephoned from H.F. D/F stations to group operations officers, who gave the necessary information to the fixer stations. The bearings obtained by the fixer stations were plotted, and the fix was passed to the aircraft.[2] Redundant operators from Fighter Command were transferred to man the fixer stations.[3] Although the system proved of value in helping to deal with the large number of calls for assistance during the early 'thousand bomber' raids and similar operations, it was never widely used, and was suspended because of a shortage of operators in No. 4 Group as early as October 1942.[4] The system was finally discontinued when Gee became firmly established.[5]

That D/F stations should be forced to close for want of operators was surprising in view of the number transferred from Fighter Command and of the output of the radio school, but, in fact, Bomber Command was expanding at such a rate that all these operators were absorbed in manning new stations. In October 1941, it was agreed that all operational airfields, including satellites, be provided with H.F. D/F. Seven of the first 31 satellite D/F stations had been sited by November 1941, leaving 24 outstanding and a balance of approximately 80 more to be dealt with subsequently. By November 1942, 123 H.F. D/F stations had already been installed in Bomber Command, and an additional 75 were scheduled for installation in 1943.[5]

In all commands, H.F. D/F stations, other than those equipped with cathode-ray sets, were equipped with Marconi DFG. 12, of which there was a permanent

[1] A.M. File CS.8571. In addition five were allocated to existing regional control centres, one to Tangmere for a new regional control centre, and one to Coastal Command.

[2] No. 1 Group O.R.B., January 1942.

[3] A.M. File CS.8571.

[4] No. 4 Group O.R.B., October 1942.

[5] A.H.B./IIE/75A.

[5] A.M. File CS.8571. The figures include D/F stations transferred or scheduled for transfer to the United States Eighth Air Force.

type and a transportable type. The set operated on both W/T and R/T, although R/T was not often used outside Fighter Command. However, in March 1941, two new D/F ground installations designed by the Marconi company to replace the DFG. 12 made their appearance.[1] They were the DFG. 24, which took the place of the permanent-type DFG. 12, and the DFG. 25, which superseded the transportable-type DFG. 12. The sets were designed as a result of the experience gained in the preceding years, and the company claimed that all weaknesses had been corrected. A feature was that it was not possible for reversed sense to be given except through extreme negligence on the part of the operator. Previously the firm of Marconi had designed a low-power set specially for satellite use, the P.3. It had been accepted on the assumption that aircraft would normally obtain main homing bearings from the parent station and change over to the satellite at short range, but it proved unreliable at night even at short range and was withdrawn in favour of the new equipment. However, due to slow production, delivery of the new receivers lagged behind the completion of new airfields.[2] Of 16 airfields due to be completed in the period March to May 1942, receivers were installed in time for the opening date at only four. The position improved in June, when 15 more receivers became available.

The policy of siting D/F stations so that they offered as little obstruction as possible while being close enough to the airfield to offer ZZ facilities was so successful that, in December 1939, of 30 Bomber Command bases in use or under construction, all but six had their H.F. D/F stations sited so as to be suitable for ZZ landing approaches and in each of the outstanding six it was possible to find an alternative at a nearby base, or to site the second D/F station to allow ZZ approaches to be made.[3] This meant that at that time virtually all Bomber Command bases were equipped for ZZ landings. A complication arose in 1941, however, when considerable difficulty was experienced in the siting of D/F stations because the main runways were being extended at certain airfields.[4] Since ZZ landings were not attempted unless visibility exceeded 1,000 yards, Headquarters Bomber Command considered that a site 800 yards from the 1,600 yard mark of the main runway, assuming it was projected to this distance, was close enough to allow good control of ZZ landings. The Air Ministry went even further and agreed that the requirement would be met if the ZZ hut was situated on the airfield perimeter. With the introduction of Standard Beam Approach at all operational airfields, the siting of the H.F. D/F station on the axis of the main runway became no longer necessary. By early 1942, ZZ was in use only at No. 2 Group stations and satellites and at certain O.T.Us. The replacement of ZZ by S.B.A. had a secondary advantage in that some of the congestion on high-frequency was relieved ; aircraft requiring homing had sometimes been unable to obtain sufficient attention because the D/F station was engaged in carrying out ZZ procedure with another aircraft.[5]

A reduction in the number and importance of H.F. D/F stations became inevitable as Gee became more widely used. Their use for homing, for instance, almost ceased, although the Service was maintained in an attenuated form until the end of the war, as a safety aid and communication channel.[6] In

[1] A.M. File S.38120.
[2] Bomber Command File BC/S.20489, Part II.
[3] A.M. File S.38120.
[4] A.M. File S.38120.
[5] A.M. File S.2712.
[6] A.H.B./IIE/76A.

January 1943, Headquarters Bomber Command suggested that the abolition of the flying control H.F. D/F installation at bomber bases could be effected without detriment to the safety of aircraft and with considerable economy in personnel and equipment, the dual role being well within the scope of one D/F station; 16 stations were closed as a result. By December 1944, when the Air Ministry carried out a review of H.F. D/F policy and requirements in the United Kingdom, the total number of installations still in use in Bomber Command had been reduced to 64. The scale of equipment included one installation at each operational base and one at each O.T.U., a reduction of fifty per cent. The importance of all wireless aids to navigation was steadily decreasing with the increasing use of radar aids, and future Bomber Command policy had been outlined at an Air Ministry meeting the previous month, when it was agreed that on the introduction of the complete V.H.F. R/T scheme all H.F. D/F stations remaining in Bomber Command could be given up.

From 1939 to the summer of 1942 H.F. D/F was of vital importance to Bomber Command, as a method of control, a means of homing, and for a short while as a fixer service. The stations gave good service, and although care had to be exercised in homing from over 100 miles, it was soon found that good homings were possible well outside this limit.[1] Although congestion on high frequency raised many problems as Bomber Command expanded and aircraft of Allied air forces joined in the offensive, H.F. D/F would undoubtedly have retained its usefulness to the end of the war but for the advent of Gee.

When the R.A.E. produced the specifications for the Marconi DFG. 12 receiver in 1936, it was expected that the equipment would be replaced by a cathode-ray set in due course. In point of fact nearly three years elapsed between the specification and Service trial stages of cathode-ray D/F equipment so that nearly all H.F. D/F stations in Fighter Command up to 1941 were of the radio-goniometer type. From 1941 onwards, following the general introduction of V.H.F. R/T in Fighter Command, all aircraft were fitted with the TR. 1133 in succession to the TR.9, and V.H.F. D/F ground equipment replaced the DFG.12. The limitations of H.F. D/F in Fighter Command arose mainly from the inadequate performance and range of the TR.9 and an insufficiency of channels.[2] Very few complaints were made about the operation of the ground stations, although there were reports of inconsistencies at first.[3]

In Coastal Command, H.F. D/F stations were established by the outbreak of war at all bases, and by November 1940 the organisation consisted of stations at Leuchars, Thornaby, Dyce, Pembroke Dock, St. Eval, Down Thomas, West Freugh, Felixstowe, Catfoss, North Coates, Bircham Newton, Thorney Island and Detling. Later all 'Type One' flying control stations in the command were equipped with two installations, and these, together with one installation at each of the 'Type Two' flying control stations and the O.T.Us., made a total of 67 stations in use in December 1944.[4] The intention then was to

[1] A.H.B./IIE/75A.

[2] *See* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception', for full details.

[3] A.M. File S.47712.

[4] 'Type One' stations had full control facilities including V.H.F. D/F, H.F. D/F on control and station frequency, Darky watch, and S.B.A. and/or B.A.B.S. 'Type Two' stations might have all or any of these facilities except H.F. D/F on control frequency.

retain all the installations pending the general introduction of V.H.F. R/T, which would not take place until the Bomber Command programme was completed, and could not therefore be expected before 1946. The requirement for H.F. D/F did not lapse in Coastal Command with the introduction of radar aids to the same extent as in Bomber Command owing to the many operations carried out beyond the range of Gee and Loran chains.

A very economical and flexible H.F. D/F organisation was maintained in Flying Training Command, stations changing from the normal W/T frequency to an R/T frequency as required. Much of the flying was solo flying in twin-engined aircraft which kept within R/T range of base. For training flights over the Irish Sea the command maintained a control centre at Ramsey, Isle of Man, but this had no fixer service, maintaining its position plots by monitoring H.F. D/F stations situated at airfields around the Irish Sea and by reports passed from aircraft. By 1944, approximately 50 H.F. D/F stations were in use in Flying Training Command.

Transport Command was formed in March 1943, at a time when all radar aids were being concentrated in Bomber Command, and it was therefore inevitable that the main system of navigational aid should be H.F. D/F. In view of the high standard of flying safety to be aimed at in a command the main duty of which was the carrying of passengers, it was natural that demands for H.F. D/F installations should be heavy. By December 1944, the total number of installations in operational use was 21, in addition to nine at O.T.Us. Transport Command also used three long-range cathode-ray networks totalling twelve stations, and three chains of Training Area flying control special fixing services comprising nine stations. However, the majority of Transport Command flights were made overseas on the reinforcement routes. The Transport Command H.F. D/F policy resulted in recurring demands for equipment, personnel, and frequencies with each expansion in operational responsibility, but the Air Ministry was unable to provide any alternative system until the supply position enabled emphasis to be transferred from wireless to radar aids. However, by the end of the war, radar was in general use in Transport Command, and investigation of the possibility of a reduction in the number of H.F. D/F stations was begun.

M.F. D/F and Identification

During the period 1939 to 1942 the M.F. D/F organisation using Marconi DFG.10 ground equipment, as the only long-range radio navigation system available to Bomber Command other than the cathode-ray system, was the most important of all radio aids to navigation. A common-user service which operated in the 300 to 400 kilocycles per second band, it was designed to give bearings and fixes up to the limit of range. The general coverage provided a good service all round the coast and inland, and the accepted range at a normal operating height of 7 to 8,000 feet was 350 miles.[1]

[1] R.A.F. aircraft based in France were able to use an existing civil M.F. D/F organisation which was divided into two sections. One consisted of 23 stations, 15 of which were equipped with Adcock, and the other of six stations used mainly for identification. The first operated on 333 kilocycles per second, and the second on 330 kilocycles per second with an alternative frequency of 300 kilocycles per second for use if interference by the enemy was experienced. An R.A.F. system, to consist of three stations operating on 309 kilocycles per second, was not completed by the time of the evacuation.

At the beginning of the war the M.F. D/F service had an important function which had nothing to do with direction-finding assistance to aircraft; identification of friendly aircraft crossing the English coast.[1] The whole organisation was split in two to cope with the requirement, leaving the number of stations available for their real purpose dangerously small.[2] An aircraft returning from an operation, and in the early days many operations were simply reconnaissance by a single aircraft, called the control station of its M.F. identification section and passed what was known as its movement serial indicator; the position of the aircraft was fixed and its identity verified. Later, when the movement serial indicator was abolished, aircraft relied on call-signs only for identification. Call-signs were entered on the appropriate pre-flight papers and the information forwarded to the D/F stations concerned.[3] The fix was passed to the filter room at Headquarters Fighter Command, where it was related to information from R.D.F. sectors reporting the approach of aircraft. As yet there was no automatic identification device available. The system worked fairly well, but it had inherent weaknesses. A wireless operator for various reasons might be unable to pass the message; also, when more than about six aircraft returned at the same time, congestion resulted. But in general, the M.F. D/F organisation proved itself well able to meet the operational requirements of the period. Comparatively few aircraft were available for bombing operations until early in 1941; the bomber effort was sustained mainly by the few Blenheim squadrons of No. 2 Group and the Wellingtons and Hampdens of Nos. 3 and 5 Groups, and aircraft could be certain of getting all the assistance they wanted.[4]

A third and vitally important function of the M.F. organisation was the distress procedure. Throughout the war, aircraft wireless operators were strongly advised to send S.O.S. messages on M.F. The chances of two or three snap bearings producing a fix were much higher on this service than on any other, and the majority of successful air/sea rescue operations were based on M.F. fixes taken before the aircraft ditched.

There was, however, one qualification in the use of M.F.—security. It was thought that frequent transmission might render the service capable of use by enemy aircraft, and on the outbreak of war Headquarters Fighter Command was given authority to instruct M.F. transmitter stations to close down or to restrict transmissions if enemy aircraft were known to be within 50 miles range. When ordered to close down or reduce transmissions to a minimum, stations arranged for their traffic to be carried on by another station or section which was not so restricted. This was all right when enemy raids were concentrated in one area and our bomber force was operating in small numbers, but when enemy raids were scattered over wide areas and Bomber Command was operating on a large scale it was difficult to find alternative M.F. stations. But the situation was not allowed to reach a stage at which the safety of our aircraft was jeopardised, the risk of bombing being regarded as more acceptable than the risk of losses in Bomber Command.[5]

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[1] A.H.B./IIE/75A.

[2] Sections F, G, H and J were reserved for identification and for D/F fixes in emergency only. Section D (Heston, Hull and Newcastle) was reserved for Bomber Command. Sections A, B, C and E, although primarily intended for Coastal Command, were also used by Bomber Command in emergency.

[3] Coastal Command Signals Review, Volume 1, No. 2, February 1944.

[4] A.H.B./IIE/75A.

[5] A.M. File S.45337.

Although as the war progressed the introduction of radar aids tended to reduce the number of M.F. fixes asked for, the older generation of navigators found it hard to regard this service as anything but the basic navigational aid, and indeed it was still giving tremendous service late in the war.[1] The service was extremely accurate, as an analysis made in September 1943 of some 200 'cocked hats' from two different M.F. D/F sections showed.[2] An allowance was made in each case for the varying angles of cut and distances from D/F stations, and the final figure arrived at as an average error for first-class bearings was plus or minus two degrees. The proportion of the three classes of bearings varied greatly with distance, but otherwise was the same from station to station and almost the same during day or night. For distances up to 100 miles, 90 to 95 per cent of bearings were first-class and only 0·5 per cent third-class; at greater distances the proportion of first-class bearings fell as that of third-class bearings rose, until at 400 miles 75 per cent were third-class and only 10 per cent first-class. One reason for the falling-off in class of bearing with distance was that as distance increased the received signal level more nearly approached the noise level, making an exact determination of bearing more difficult; thus the variations depended to some extent on the power of the aircraft transmitter. In addition, because of geographical limitations, and particularly the inadequacy of the length of the British Isles as a baseline, it was not possible to arrange each set of stations so as to ensure reasonable accuracy at extreme ranges; as range increased accuracy decreased, particularly over Germany.

During the early part of 1942 it was not unusual for that part of the M.F. D/F organisation which dealt only with Bomber Command operational aircraft to give as many as four fixes per aircraft operating. With 100 aircraft operating, this involved up to 400 fixes over a period of perhaps five hours, or 80 fixes per hour. Owing to the signalling procedure involved in getting a fix, any one section could not be expected to give more than about 20 fixes per hour, and because of the baseline factor not more than five sections could be made available to cover any one operation. So it was evident that the organisation was reaching the limit of its capacity when, in the absence of another system, more than about 100 aircraft were likely to need help. If an emergency arose due to bad weather or other causes the rate of requests for fixes might be so high over a short period that congestion and delay would result.[3]

Difficulties were soon encountered in the method used for identification of returning bombers. Aircraft W/T operators maintained watch on the operational frequency, which was in the H.F. band, throughout the flight until within 100 miles of the English coast on the return journey, except for any change of frequency necessitated by calls for D/F assistance. At 100 miles from the coast they were supposed to change to M.F. and to send the identification signal, but within a few days of the outbreak of war Headquarters Fighter Command was reporting that the identification signals were not being received.[4] The difficulties of aircraft W/T operators in the early days affected the efficient working of the identification procedure. The process of changing coils and retuning was a complicated one with the equipment in use at that time, and this of itself made operators reluctant to interfere with the setting of their equipment once they were satisfied that it was properly tuned. Wireless was

[1] A.H.B./IIE/75A.
[2] C.C. O.R.S. Report No. 251, 18 September 1943.
[3] A.H.B./IIE/75A.
[4] A.M. File S.40818.

being used to obtain fixes and homing bearings, to listen out for operational messages, and as a means of identification, but even so, W/T silence was observed for the major part of any sortie, and an operator's main concerns were to be sure not to miss any operational message, and to be able to break W/T silence in emergency and be sure that his signals would be received at once. Signals failures were frequent, and operators developed an antipathy to any procedure which disturbed their equipment when it was correctly set up and in apparent good order.

Under the principle that efficient intercommunication can only be achieved if both ends of the system used are under the same control, the M.F. D/F identification stations were taken over by Headquarters Bomber Command. This at least meant that responsibility for failure of the identification procedure could be quickly tracked down. But, in addition to signals failures, there was another factor which militated against successful operation of the procedure. The errors arising in navigation on long operational flights over territory where meteorological forecasts were unreliable were greater than had been expected, and any system of identification which depended on bomber aircraft being able to fix their position over the sea after a long operational flight could never be more than makeshift with the aids available at that time.[1] Nevertheless, great efforts were made, and following a conference at Headquarters Fighter Command on 7 September 1939, after which the importance of the correct observance of identification procedure by aircrews of Bomber Command was again stressed, the percentage of returning bombers identified rose to 75. This was a great improvement, but the basic need for a system by which friendly aircraft were automatically identified on the Home Chain radar screens remained. Changes in the disposition of the stations were made in the light of experience, and as by December 1939 aircraft were being equipped with I.F.F. at a steady rate, its early introduction on a widespread scale was anticipated.[2]

The identification procedure had originally been devised in the light of two assumptions: transmission from M.F. D/F stations would be limited to a minimum to deny their use to the enemy as beacons; and acknowledgments of identification messages by the D/F ground stations would overload the service. Experience in the first six months of the war suggested that the danger of enemy use had been exaggerated, and that since most aircraft called some section of the M.F. D/F service for a fix either before or after identification, that call could be used for identification purposes without causing congestion. All D/F sections could thus be thrown open for a combined security/identification service, removing the unnatural divisions which existed. A new system on these lines was brought into force, in Bomber Command only, on 15 June 1940.[3] It was intended to pave the way for comprehensive introduction of the I.F.F. system, with a great easing of the burdens of the air wireless-operator, who would no longer have to change frequency to identify, or to carry out protracted identification procedures. It was considered that the advantage gained by lightening his task, and thus improving chances of successful homing, greatly outweighed the possible disadvantage that the enemy might be able to make some use of the ground transmissions. But in

[1] A.M. File S.40818.

[2] A.M. File S.40818.

[3] A.M. File S.40828, Part II. *See also* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

spite of these hopes, ten days later, on 28 June 1940, the new arrangements were cancelled and separate M.F. sections for security and identification were again allotted to each group.[1]

By October 1940, 90 per cent of Bomber Command aircraft, not including Battles, were fitted with I.F.F., and the average nightly serviceability of I.F.F. equipment was believed to be about 90 per cent.[2] Nevertheless, the identification procedure was still being used in addition, and was in fact revised and re-promulgated in November 1940. Instructions for the use of I.F.F. were included, but its use did not yet raise the obligation to send the W/T identification signal. Trials were carried out by Bomber and Fighter Commands in collaboration to test the suitability of I.F.F. as the primary means of identification. As a result, from 1 April 1941, aircraft were obliged to identify themselves by W/T in the following circumstances only:—

(a) When Form 'J', the form giving details of the flight, had not been submitted in advance.
(b) When aircraft were not fitted with I.F.F.
(c) When I.F.F. was not functioning correctly.
(d) When aircraft were flying below 2,000 feet.
(e) When aircraft were seriously off course or off schedule.

M.F. Beacons and Aircraft Loops

The need for a radio aid to navigation which did not involve transmission by aircraft had long been recognised, and much of the research and development carried out during the inter-war years was directed to this end. A final decision was made at the first annual D/F conference in 1934 to concentrate on development of D/F loops in aircraft in conjunction with that of ground beacons. However, on the outbreak of war, security considerations had outweighed all others and no beacons were available to R.A.F. aircraft based in the United Kingdom or in France. Much of the development work carried out on the loop, and the production capacity taken up in building and fitting it, was therefore set at naught. Most twin-engined aircraft carried a D/F loop but there were no signals for it to receive. By October 1939 a number of continental broadcasting stations were being used in conjunction with the D/F loop by Bomber Command, notably Quotala, Kalundborg, Hilversum, Kootwyk, Brussels and Beromunster. By the end of that month it had also been established that certain enemy beacons were operating on a recurring system, so that it could be forecast which would prove of value to aircraft operating over enemy territory. Headquarters Bomber Command had not the facilities for compiling the data from which a forecast could be made, and asked the Air Ministry to issue a daily bulletin, combining this if possible with the neutral stations' bulletin already being issued. It was stressed that aircraft were without any assistance from beacons or broadcasting stations in Great Britain and Northern Ireland, while the neutral stations were few in number and in any event closed down at midnight, thus making their value extremely limited.[3]

A conference was held at the Air Ministry on 17 November 1939 to discuss means of utilising enemy and neutral transmitters for loop D/F, the policy to be adopted with regard to erecting beacons in the United Kingdom, and

[1] The allocation of M.F. D/F sections is shown at Appendix No. 14.
[2] A.M. File S.40818, Part II.
[3] A.M. File S.2712.

associated technical problems. The conference decided that efforts to utilise enemy and neutral transmitting stations should be made, and that while a system of fixed wireless beacons in the U.K. for general use was undesirable, an organisation should be established to provide suitably located emergency beacons which could be brought into use, under careful control, for short periods, and that the possibility of using mobile beacons for such an organisation should be investigated. As an interim measure, the Admiralty agreed to make transmissions available from the naval W/T station at Cleethorpes. Arrangements were also made for the de-spoiling of the B.B.C. transmitters at Manchester and Borough Hill so that they could be used as M.F. beacons in emergency pending the introduction of the new organisation.[1]

The need for training wireless operators in the use of D/F loops and M.F. beacons was recognised, and a beacon intended primarily for training purposes began transmission from Andover on 17 January 1940. The overriding responsibility for closing down the beacon at any time to deny its use to enemy aircraft lay with Headquarters Fighter Command. If it became necessary to use the beacon for operational purposes, Headquarters Bomber Command consulted the controllers at the Fighter Command Operations Room, and if the local situation warranted it, the beacon was switched on. For normal training purposes, precautions were taken to restrict the range to 120 miles, and to ensure that periods of transmission were irregular.[2] A summary of reports on the operation of the Andover beacon up to 13 February was prepared by Headquarters Bomber Command, and it showed that because of bad weather, flying had been greatly restricted and very little experience had been gained with the beacon. R.A.F. Andover reported on 26 February that the beacon had been closed down on seven occasions on orders from Headquarters Fighter Command, and a later report from Headquarters Bomber Command on 4 March gave an instance where homing had been successfully carried out; Headquarters No. 3 Group considered that the beacon services would prove invaluable.[3] Further reports showed that operators generally were gaining confidence although all groups complained of weak signals; two aircraft of No. 3 Group had been navigated back to base by use of the beacon after W/T transmitter failure.

At the end of April 1940 beacons operated on request at Andover, Borough Hill and at Odiham, installed as a second training beacon. The Admiralty station at Cleethorpes could be used by the R.A.F. on request, and other Admiralty stations at Rosyth and Scapa could be used as beacons when they were transmitting. A new chain of beacons built to Air Ministry specification was shortly to be completed, and was intended primarily for training purposes. The first two stations, at Pembroke Dock and St. Athan, opened on 24 April, a third at Evanton opened on 29 April, and a fourth at Kinloss on 5 May. The B.B.C. transmitters at Manchester and Borough Hill were brought into this synchronised scheme, but were reserved for emergency use by operational aircraft and were not used for training purposes. Arrangements were made for the use of two other B.B.C. transmitters when no alternatives were available. A system of mobile beacons for operational aircraft, which was recommended by the beacon conference of November 1940, was in preparation.

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[1] A.M. File S.2712. [2] A.M. File S.1520. [3] A.M. File S.2712.

The Air Ministry decided in December 1940 that four beacons were to be constructed on a mobile basis, two in the Yorkshire area and two in East Anglia; the total was later increased to six. Sites were selected which were not too near vulnerable points although near enough to the area they were designed to cover. High masts with good aerials were erected, and the sites were connected by landline to Headquarters Bomber Command so that instructions for switching on and off could be given quickly. Arrangements were made so that the disposition of the transmitters and their frequency and call-sign could be interchanged to cause the maximum possible difficulty to an enemy endeavouring to make use of them. Three stations worked quasi-synchronously in the same way as the B.B.C. medium-wave stations. The separation between the three station zones was such as to leave the utility of a station as a beacon unimpaired within a radius of 50 miles, while the transmissions were so synchronised that the transmitter locations could not be fixed by D/F ground stations in Germany. As there were two groups of three stations they could periodically change partners, so that even if the three stations of a group were all identified on one day, the information would be useless to the enemy on succeeding days.

The mobile beacon system was completed in September 1940, and the two groups were:—

(*a*) *Beacon Group* ' *A* '.

(i) Wolsingham (approximately 10 miles north-west of Bishop Auckland).

(ii) Ravenscar.

(iii) Eavestone (approximately 6½ miles south-west of Ripon).

(*b*) *Beacon Group* ' *B* '.

(i) Frithville (approximately 4 miles north of Boston).

(ii) Salthouse (3 miles north of Holt, Norfolk).

(iii) Little Downham (approximately 2½ miles north-west of Ely).

In practice, one transmitter in each group worked at any given time, transmitting the call-sign of its group followed by a long dash. The beacons operated between 1900 and 0700 hours, subject to overriding control by Headquarters Fighter Command; they were not operated by day except at the special request of Headquarters Bomber Command. Aircraft carried only such beacon information as was necessary to cover the duration of a flight.[1]

Fortunately it was not until the end of 1941 that the enemy began to use a beacon-spoiling system similar to that used in the United Kingdom, and full use could be made of enemy beacons during the period before the introduction of radar aids such as Gee. But even after 1941, Headquarters Bomber Command was generally able to keep crews informed of changes in the German system; when a new enemy beacon system came into force on 15 June 1942, the rota in use was broadcast continuously on a special frequency by Headquarters Bomber Command, and the beacons were still used with success during operations.[2]

The standard reached with use of the D/F loop in Bomber Command during the years 1941/42 was fairly high, although errors such as not setting the loop to zero, and tuning in to the wrong beacon, still occurred.[3] Operations carried

[1] A.M. File S.2712, Part II.

[2] No. 3 Group O.R.B., 1942.

[3] No. 4 Group O.R.B., June 1942.

out at maximum range by Stirling aircraft of No. 3 Group were often greatly assisted by the use of enemy and neutral beacons, while on some trips the lack of suitable enemy beacons contributed to navigation failures. Great use was made of the loop by aircraft of No. 1 Group, and analysis of 239 sorties in January 1942 revealed that the average number of bearings taken per aircraft was eleven. A survey of the accuracy of loop bearings carried out by Headquarters No. 1 Group showed that for every reliable bearing received, it was estimated that there was also one unreliable bearing which could be used for approximation, and one useless bearing. The only satisfactory method was to use the mean of six bearings as a single position line, disregarding the obviously bad readings. A summary of general errors in the same group showed that there was still failure in some degree to use the navigational aids available, and fatal accidents still occurred which were attributable to navigators conducting sorties on dead reckoning, using forecast winds only. It was impressed upon crews that forecast winds were issued purely as a guide and that they should never be considered by navigators as more than an approximation, but as late as February 1942 navigators were still relying on them, with resultant navigational errors. However, navigation on No. 1 Group operations at about the same time was carried out largely by use of D/F loop bearings and fixes.[1] Another point which operational experience brought to light was that failure to obtain frequent loop bearings often resulted in an isolated loop bearing or fix being ignored by the navigator because the discrepancy between loop fix and D.R. position was so great, and the need for loop bearings to be taken and plotted at frequent intervals was made evident.

On 2 September 1944, Headquarters Coastal Command raised a requirement, approved a few days later, for the installation of two M.F. beacons, one in the Shetlands and the other on the west coast of France. A beacon in the Shetlands had long been a requirement, but objections had previously been raised by the naval authorities on security grounds. The objections were considered to be no longer valid, and although an early establishment of Loran in the area was expected, provision of a high-powered M.F. beacon was still thought to be desirable. The need for the second beacon had arisen paradoxically enough through the success of the Allied liberation armies. As a result of the fall of the Brest peninsula, the *Sonne* beacon at Quimper had been destroyed by the Germans. Great use had been made of the beacon by Coastal Command aircraft flying over the Bay of Biscay beyond Gee range.[2]

The installation of retractable D/F loops in Harrow, Whitley, Battle, Blenheim, Anson and Wellesley aircraft had been recommended by the Aircraft Equipment Committee as early as June 1936. However, the early designs were not ideal, and difficulty was encountered, particularly in Blenheim aircraft, because above certain speeds the slipstream was apt to cause the mechanism to jam. A modification to improve the loop movement was given a high priority, but this was later reduced owing to other urgent needs, and the Blenheim squadrons began operations without a satisfactory loop installation.

In addition to the technical difficulties, there were associated tactical problems. Headquarters Bomber Command had stated a requirement for a system of

[1] No. 1 Group O.R.B., January 1942.

[2] Coastal Command O.R.B., September 1944.

M.F. beacons for loop navigation, but early in the war the view prevailed that such beacons were too susceptible to use by the enemy. However, Bomber Command experience in the first weeks of the war emphasised the need for additional aids to navigation; the duties of the wireless operator/air gunner during that part of an operational flight when loop bearings were most needed kept him at his guns, and it was therefore for consideration whether a navigator-operated loop could be installed. An overriding factor was that Headquarters Bomber Command would not accept any installation, however efficient in other ways, which affected the speed or performance of the aircraft.

As a result of an unfavourable report on the early installations in Blenheim aircraft of No. 2 Group, representatives of the Royal Aircraft Establishment visited the Bristol Aeroplane Company on 21 November 1939 to inspect installations at the works, and reported favourably on them. However, the Chief Signals Officer of Bomber Command met representatives of both the R.A.E. and the Bristol Aeroplane Company at Wyton six days later, and as a result of the meeting and trials in the air he had no hesitation in recommending to the Air Ministry that no more aircraft be fitted with the existing layout. A few days later, on 6 December 1939, Headquarters Bomber Command asked for consideration to be given to the provision of a navigator-operated D/F loop installation in Blenheim aircraft. Meanwhile, work on installation of the loop in Blenheim aircraft was stopped. Trials and examinations of the old installation were carried out at the R.A.E. and the B.A.C., and a meeting was held at Bristol's on 8 January 1940 to find possible ways of meeting Bomber Command requirements. It was found that design and incorporation of a modification to move the loop to a position where it would be accessible to the navigator could not be completed before the Blenheim construction programme had reached an advanced stage; extensive retrospective fitting would then be necessary. In fact, a satisfactory control for the navigator within a reasonable time was out of the question. On the other hand, Bristol's promised that the existing installation could be brought to an acceptable standard quickly.[1] The Air Ministry had already agreed to the provision of a system of fixed and mobile M.F. beacons, so that an efficient D/F loop operated by the wireless operator would at least provide homing facilities, even though its use would still be restricted by the wireless operator's gunnery duties throughout most of a flight. It was therefore decided that an unsatisfactory installation at a unit should be selected by Headquarters Bomber Command and should be brought up to an acceptable standard by the Bristol Company. The installation would then be thoroughly tested, and, if accepted, would be used by the firm as a standard for all other installations.[2] In February 1940 trials of a modified loop were carried out for several days but the results were very little better than those previously obtained, and it seemed clear that the existing system of mounting and remote control was impracticable because of distortion produced by slipstream pressure. The need for a navigator-operated loop was again stressed and it was considered that if it could not be supplied the possibility of fitting loops in Blenheims should be abandoned. However the Bristol Company was confident that a modification could be made to the existing installation which would satisfactorily overcome the mechanical defects so far experienced; and the Air Ministry did not want existing arrangements for the installation of loops in

[1] A.H.B./IIH/241/10/1. Bomber Command File BC/S.20758/3.
[2] A.H.B./IIH/241/10/1.

Blenheims cancelled until the modification had been tested. The A.O.C.-in-C., Bomber Command was not prepared to sacrifice speed for the navigational assistance offered by the loop, and thought that the Blenheim might become obsolete before the navigator-operated loop could be produced, so that its development would be absorbing productive capacity which could be more usefully employed elsewhere. It was shown that the loss of airspeed with the loop retracted was negligible, and with the loop extended was not more than 3 m.p.h. at maximum speed, and it was established that the Blenheim was likely to be in service for some time. It was 21 March 1940 before the A.O.C.-in-C. was able to recommend the continuance of action to make the wireless operator's loop satisfactory and efficient. At the same time development of the navigator-operated loop which would ultimately replace it was requested.[1]

An aircraft at West Raynham was allocated for loop modification, but when the installation was air-tested rotation of the loop became extremely difficult at 190 m.p.h. and it locked completely at 210 m.p.h. On the same day, 9 April 1940, the Air Ministry was informed by the Bristol Company that the loop was considered satisfactory and ready for any examination. In the next few days further modifications were incorporated and on 25 April representives of all interested parties tested the equipment. As a result it was decided to accept the loop in its final modified form if each loop passed an air test at 200 m.p.h. Arrangements were accordingly made for a B.A.C. working party to modify existing loops to the standard required and to install satisfactory loops in aircraft deficient of them. The No. 2 Group squadrons were given priority, and the working party arrived at Wyton on 6 May 1940. At the end of June, however, it was reported that no further fitting was being done, that the loops already installed were not being used, and that in most instances they suffered from all the defects of the original rejected installation.[2] In the following month Headquarters No. 2 Group asked if, with the employment of Blenheim squadrons on night operations, the aircraft could be provided with navigation aids similar to those installed in heavy-bomber squadrons, and especially an effective D/F loop, so that use could be made of United Kingdom and enemy beacon systems. Fitting of the new Marconi receiver, the R.1155, with a new Marconi D/F loop, had begun, but the set was not yet available in sufficient numbers to equip all Bomber Command aircraft. In addition, the requirement for a navigator-operated D/F loop still remained. The Air Ministry favoured the provision of a second Marconi R.1155 for this purpose, but it was not expected that the set would be available in sufficient quantities to enable installations to be made at the rate of two per aircraft until February 1941.[3] Five months later, in December 1940, following two serious navigation failures involving experienced crews, Headquarters No. 2 Group again raised the question of navigator-operated loops. The Blenheim was by then fitted with a twin-gun turret which made coil changing very difficult, so that full use of the M.F. D/F service could not be made, and the need for a navigator-operated loop was even more urgent. A trial installation of the Marconi loop was completed at Watton during the same month, but general fitting was still not possible. However, a trial installation of a Bendix D/F loop and receiver was completed at Wattisham,

[1] A.H.B./IIH/241/10/1. [2] A.H.B./IIH/241/10/1. [3] A.H.B./IIH/241/10/1.

and performance was so satisfactory that the immediate allocation of 160 sets believed to be in the country was made as a temporary measure until replacement aircraft fitted with the additional Marconi set for the navigator were available.[1] By June 1941 it was considered that the size and weight of the R.1155 precluded the installation of two of them in Beaufort and Blenheim aircraft.[2] Since the need for a navigator-operated loop was confined mainly to the smaller types of aircraft because of the gunnery duties of the wireless operator, the requirement was no longer of importance in Bomber Command.

By August 1940, Headquarters Coastal Command was expressing dissatisfaction with existing loop installations and asking for the fitting of later models.[3] The loop was then used in conjunction with the R.1082, and although a great improvement was expected with the introduction of Marconi equipment, the likely date of provision was still not known. In addition, the R.A.E. considered that it would not be practicable to fit the latest type of loop with the R.1082. A keen interest in the provision of navigator-operated loops, which had been installed in a number of Hudson aircraft fitted with the R.1082, and in all Sunderlands, in view of their long flights over the sea, had been evinced in Coastal Command, but the main interest in the operation of the loop lay in its use to home aircraft to convoys for patrol duty, to home strike forces to aircraft shadowing enemy shipping and submarines, and to home aircraft to transmissions made by U-boats.

The loop installation in Beaufort aircraft was never entirely satisfactory up to the time of the fitting of the Marconi R.1155 and ancillary equipment. In August 1941, No. 22 Squadron, based at Thorney Island, reported that owing to the large errors experienced with the Bristol loop and the short distances over which their aircraft operated, loop homing had not been employed; direction-finding by other methods had proved adequate. Up to that time, no instance had been recorded in the squadron of loop homing being of any assistance to aircraft whilst returning to base.[4] Complications arose when Beaufort Mark I aircraft, fitted with the R.1082 and Bristol loop, were required to home to a shadowing aircraft, and in March 1942 Headquarters Coastal Command reported that extreme difficulty was being experienced, and requested action which would be of immediate benefit, pending the general easing of the situation which was to be expected when more receivers R.1155 were in use. The R.A.E. considered that the problem of quadrantal error, which worried Headquarters Coastal Command, was really a small handicap, as although the first few bearings taken might be incorrect, when an aircraft settled down to follow a series of bearings, quadrantal error would be negligible. Homing with the R.1155 was thought to be possible up to 60 to 80 miles and more, but although good results might be obtained at times with the R.1082, the equipment could not be regarded as being generally satisfactory for homing to another aircraft, mainly because of lack of signal strength and the width of minima. No satisfactory solution was found to the Coastal Command problem, but with further deliveries of aircraft fitted with the R.1155 and Marconi loop the situation eased.[5]

[1] Difficulties of fitting a D/F loop, prior to the production of the Marconi T.1154/R.1155 and ancillary equipment, were not confined to Blenheim aircraft. Precisely the same trouble was experienced with Hampdens.

[2] Coastal Command File CC/S.14126.

[3] Coastal Command File CC/S.14126.

[4] Coastal Command File CC/S.14126.

[5] Coastal Command File CC/S.14126.

In November 1942 Headquarters Coastal Command began considering the possibility of removing the D/F loop from all aircraft in the command, but Air Staff opinion was not unanimous. On 18 February 1943, at a conference known as the 'Christmas Tree' conference because its object was the removal of all but absolutely essential equipment from aircraft, it was decided that the Coastal Command D/F loop requirement should be the subject of further investigation so that definite recommendations might be made for continued installations or immediate withdrawal. On 8 March 1943, it was decided that the D/F loop could be removed from all Beaufighters and Wellington Mark XI and XII aircraft but was to be retained in reconnaissance aircraft because the majority of Allied shipping was not equipped with Rooster for A.S.V. homing.[1] The D/F loop was, in fact, given considerable use in Coastal Command as a radio aid to navigation until the end of the war.

In November 1944 the Coastal Command Development Unit completed an analysis of loop bearing errors.[2] It showed that good results were obtained at ranges up to 200 miles by day, but that fairly large and random errors could be expected at night. Over 200 bearings, obtained at varying ranges and heights, were examined. By day, at 100 miles range and 2,000 feet aircraft height, errors varied from plus 1½ degrees to minus 7 degrees, with an average of 2·1 degrees; at 170 miles and 3,000 feet, errors varied from plus 2½ to minus 5½ with an average of only 1 degree; at 300 miles the average error rose to 10 degrees. By night, the best results were obtained at a range of 200 miles and a height of 3,500 feet when errors varied from plus 6 to minus 13 with an average of 3·6 degrees. Because both height and range were changed together, the analysis gave no real indication of the effect of height on accuracy.

Homing Applications of Aircraft Loops

Shortly after the outbreak of war a requirement arose in Bomber Command for a method to enable aircraft of a strike force to home from a distance of about 20 miles to a reconnaissance aircraft engaged on shadowing an enemy naval unit, when ordinary navigation systems had been used to position the strike force at that distance from the target.[3] Exercises had been carried out at the request of the Admiralty early in 1939 with discouraging results but towards the end of the year the practicability of using an aircraft D/F loop in order to home to M.F. transmissions made by another aircraft was tried out. The active interest of the Admiralty was again stimulated by the report of an attack by enemy aircraft against H.M.S. *Juno* on 17 October 1939, in which it appeared that air-to-air D/F or homing was used for directing a strike force to shadowing aircraft. Air Ministry interrogation of a prisoner from a *Ju. 88*, with other information supplied from Intelligence sources, indicated that German bombers were being homed to reconnaissance aircraft by M.F. D/F. Results of the Bomber Command homing trials indicated that reliable air-to-air homing was possible from a range of 40 to 50 miles on M.F. when the Marconi receiver R.1155 was used. Homings could be completed to within one mile, although at very short distances indications of bearings became completely unreliable. The use of a visual indicator by pilots made homing a simple process, but it was necessary for aircraft to be flown at approximately the same height.

[1] Coastal Command File CC/S.14126. *See also* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare', for further details of Rooster.

[2] S.E.A.C. O.R.B. Navigation Appendices, November 1944.

[3] A.M. File S.2501.

For the time being, however, the majority of aircraft, especially those of Coastal Command, were fitted with the R.1082 receiver, and were not equipped with visual indicator equipment. In an attempt to find an interim method until the Marconi receiver became available in quantity, a proposal was made to use A.S.V. in conjunction with I.F.F. Experiments were carried out at Leuchars in April 1940, and the advantages of what became known as Rooster over the loop system became evident. The nature of the aerial systems was such that polarisation errors were much smaller than those obtained with loop aerial systems. The characteristics of A.S.V. provided range measurement and identification as well as homing. Jamming and interference were much less likely. These facts were summarised at the time by Mr. R. A. Watson Watt, who recommended, as an emergency measure, the fitting of 36 I.F.F. sets to work with A.S.V. for homing. He considered that, although homing by loop on M.F. was the only sound alternative method, both systems could be regarded only as stop-gaps until the operational requirement could be met with radar. However, there were many practical difficulties in the use of A.S.V. with I.F.F., and in any event neither type of equipment was available on any large scale, so it was decided to continue with the installation of Marconi receivers and D/F loops.[1]

On 9 January 1942 an exercise was held to test the signals organisation to be used in the event of a bomber strike force being despatched to intercept an enemy surface raider in the Western Approaches, the strike force homing to a shadowing aircraft of Coastal Command.[2] The exercise disclosed certain faults in the system but showed it to be practicable, and similar exercises were carried out over a period of eighteen months so that all strike leaders in Bomber Command should be conversant with the system and have recent experience of it. It was emphasised that the success of such operations would depend on the training and ability of air crews in homing to the reconnaissance aircraft, and operational training units as well as operational squadrons were instructed to pay special attention to practice in obtaining loop bearings on ground stations and in air-to-air homing. One point revealed by the exercises was that signal strength was greatly improved when the strike force approached well below the shadowing aircraft, so that the structure of neither aircraft interposed between the trailing aerial of the transmitting aircraft and the D/F loop of the receiving aircraft.[3] This was reversed when the strike force contained no aircraft equipped with D/F loops and were receiving loop bearings from the shadowing aircraft. In some conditions a system of automatic D/F homing was used, the circumstances generally being those in which an aircraft had located an enemy force or vessel and could transmit call-signs and dashes at regular intervals so that H.M. ships in the area could home to them without breaking W/T silence.[4] The system meant that a number of ships could get bearings simultaneously, and the same procedure was used for homing aircraft, the shadowing aircraft being known as the beacon aircraft. Beacon aircraft flew as high as possible to make homing easier. The D/F procedure for homing

[1] A.M. File S.2501. In the Middle East, Wellingtons equipped with T.1154/R.1155 were able to take reliable loop bearings on shadowing aircraft at ranges up to 80 miles. Experience in the Mediterranean in 1944 also emphasised the value of W/T homing against U-boats.

[2] Coastal Command File CC/S.9105/5/1. [3] Coastal Command File CC/S.9105/5/1.

[4] Coastal Command Signals Review, Volume I, No. 2, February 1944.

strike forces to a shadowing aircraft was retained until the end of the war, although it was superseded by Gee and Loran when the aircraft were fitted with those systems and when the target was within the prescribed cover.

A good example of the smooth continuity which could be achieved when successive shadowing aircraft made homing transmissions was provided on 27 December 1943, when a Sunderland of No. 201 Squadron sent a sighting report of a blockade runner in the Bay of Biscay at 1015A, and an amplifying report a quarter of an hour later. An accurate description of the ship was included, and two Liberators of No. 224 Squadron were at once diverted to the position given. At 1122, the Sunderland was told to start making homing transmissions on 385 kilocycles per second, the homing frequency, and immediately afterwards the two Liberators were able to start homing. In the ensuing half-hour two more Sunderlands arrived at the scene of action, and at midday another Liberator and a Wellington were diverted to the scene and were instructed to home on the transmissions of the first Sunderland. By now this aircraft was approaching its prudent limit of endurance, so at 1305 one of the other Sunderlands which had made contact took over the homing transmissions, the first Sunderland returning to base after delivering its attack. Another Liberator, which had begun homing on the first Sunderland's transmissions at 1245, reached the target at 1428, and took over the homing transmissions at 1616 when the second Sunderland reached its P.L.E. The first really successful attack was carried out at 1646 by one of the diverted Liberators, the ship being set on fire. Further homing was completed by other aircraft, and at 1722 the shadowing Liberator reported that the ship had been abandoned and was on fire with 70 survivors in the boats. The final report at 1813 gave the position in which the ship was sinking.[1]

From the beginning of the war, Coastal Command aircraft found the greatest difficulty in meeting the convoys they were detailed to escort. The position of a convoy, particularly of an incoming convoy, could rarely be accurately predicted, and even when it could be, the fact that D.R. navigation was not an exact science meant that aircraft sometimes failed to make contact.[2] Long-range A.S.V. was not available in Sunderlands and Catalinas until the latter half of 1941, and the only aid to locating a convoy was W/T homing. But early in 1941, when the monthly sinkings by U-boats were at their worst, strict W/T silence was still in force, thus removing the only available aid to location.

It was recognised in May 1941 by the Director of Anti-U-boat Warfare that radio silence was defeating its own ends in that it resulted in many escorting aircraft failing to make contact, and this view was supported by the A.O.C.-in-C., Coastal Command.[3] At the same time, with the delivery of an increasing number of Catalinas from June 1941 onwards, escort further and further out into the Atlantic became possible, thus aggravating the navigation problem. Previous instructions on the meeting of convoys were therefore reviewed in August 1941, when it was agreed that all aircraft on contacting their convoy should send a signal to base giving the convoy position as a bearing and distance from a pre-arranged datum point. On the other hand, if after two hours' search a location had not been made, the signal 'Not Met' was to be

[1] Coastal Command Signals Review, Volume I, No. 2, February 1944.

[2] A.H.B. Narrative 'The R.A.F. in Maritime War'.

[3] A.M. File S.88156/1.

sent. On receipt of the 'Not Met' signal, the C.-in-C., Western Approaches decided whether or not the circumstances justified the convoy escort vessels' breaking W/T silence to home the aircraft to the convoy. If it was decided that W/T silence could be broken, the senior officer of the escorting vessels was ordered by W/T to transmit call-signs and dashes on 385 kilocycles per second at a specified time; the aircraft was similarly instructed to listen out at the specified time and to home to the convoy by means of its D/F loop.[1] This method of homing was known as Procedure 'A'. There were, of course, many other factors which affected the percentage of abortive sorties, but W/T homing was generally acknowledged to be the most reliable means of ultimately ensuring a meeting.

By early 1942, A.S.V. was becoming more generally fitted in long-range escort aircraft, but the average range from which a convoy could be recognised, about 25 miles, although of great assistance in the final location, was no help in the earlier stages of homing. The equipping of escort surface vessels with A.S.V. beacons gave promise of much greater A.S.V. range, but the rate of provision of beacons was slow, and W/T homing remained the only solution.[2] At the Admiralty Trade Protection Meeting on 6 January 1942, concern was still being expressed at the number of aircraft which failed to meet their convoys, and at the reluctance of convoy escorts to break W/T silence to home aircraft. An analysis covering the period July to December 1941 had been made of the proportion of failures of aircraft to meet convoys between 400 and 600 miles out, the range at which aircraft escort was most valuable, and it was found to be above 35 per cent.[3] Beyond 600 miles range this figure rose to 60 per cent. The navigation problem was complicated, especially in the case of incoming convoys, by the difference between the estimated position of convoys and their actual position. Further, convoys which were successfully located were only met after a long search, and it was estimated that not more than 20 per cent of effective flying time was spent with convoys. The proportion of 'Not Met' sorties continued to be depressingly high. Other factors such as weather greatly affected the figures, but it was still felt that the homing procedure left much to be desired, and during April 1942 an alternative procedure was introduced whereby the aircraft sent its call-sign and dashes on 385 kilocycles per second and the escort vessel or ship concerned took a bearing and transmitted it to the aircraft. This method was called Procedure 'B'.[4] In July 1942 its use was extended to H.F., and frequencies of 3,925 and 6,666 kilocycles per second, generally the former, were used. Much improved results were obtained with the use of Procedure 'B', which entailed less W/T signalling by the convoy; it was in fact a far more logical arrangement than its predecessor.

With the introduction of Procedure 'B', a new policy was agreed with the C.-in-C., Western Approaches:—

(a) When any convoy was being shadowed by *Focke-Wulf* aircraft or U-Boats the homing procedure was in general always to be employed.

[1] No. 15 Group Operational Instructions.

[2] A.H.B. Narrative 'The R.A.F. in Maritime War'. By early 1943 responder beacons were being fitted more generally on H.M. ships, the aim being to ensure that at least one ship in each convoy was so equipped.

[3] Coastal Command File CC/S.7011/1. Part IV and A.H.B./II/39/7.

[4] No. 15 Group Operational Instructions, Amendment No. 6.

(b) For SL, OS, HG, OG, and other southbound convoys which were not being shadowed, the homing procedure was not to be employed in normal circumstances when the convoy was south of latitude 52 degrees north.

(c) For transatlantic convoys the homing procedure was to be used as a matter of routine.

Instances occurred where aircraft failed to meet a convoy and the naval authorities considered it undesirable for the convoy escort to break W/T silence to home the aircraft. In such instances the area combined headquarters could order the aircraft to change to an appropriate M.F. or long-range cathode-ray D/F section wavelength and transmit call-signs so that its position could be fixed; the D/F control station concerned was informed whether the fix was to be transmitted to the aircraft or reported to A.C.H.Q. The aircraft sent its call-sign and dashes for three minutes, waited for one minute to see if the D/F control would pass the fix, and then reverted to its operational frequency. If A.C.H.Q. considered it advisable, the fix or further directions were then communicated to the aircraft.[1]

From July 1942 to March 1943, Procedure 'B' was used almost exclusively with the North Atlantic merchant convoys. Up to March 1943 it was used on about two-thirds of all such sorties, and subsequently it was used almost invariably.[2] The procedure was more successful on H.F. than on M.F., solely because two-way contact was established more easily on the higher frequencies. In fact, the most frequent cause of failure was the simple inability of ship and aircraft to establish two-way W/T contact. The blame for this appeared to be equally divided. In theory Procedure 'B', like Procedure 'A', was to be used only when search by D.R. navigation failed. In practice, aircraft crews were generally instructed before take-off to carry out Procedure 'B', beginning at a certain time, usually when it was estimated they would be about 100 miles from the convoy. The convoy also knew in advance that W/T homing was to be used. The only disadvantage of this interpretation of Procedure 'B' was the continual breaking of W/T silence; this prevented its use on the North Africa convoys at the time of Operation Torch, but was no longer regarded as a serious consideration in the North Atlantic. From the point of view of efficiency in meeting convoys, the practice was an improvement on the theory, since no time was lost before homing began. If the homing was successful, no time at all was lost in searching.

Experience with Procedure 'B' up to March 1943 showed that its use decreased the number of 'Not Met' sorties by about 7 per cent. The figure seemed disappointingly low, but had to be related to a number of other factors. The overall percentage of 'Not Met' sorties was roughly proportional to the distance of the convoy from the aircraft base; the percentage of 'Not Met' sorties rose as distance increased, and over the shorter distances W/T homing was seldom used. Therefore most of the additional meetings resulting from W/T homing were at the greatest distances, where an increase in escort was most valuable. In March 1943, 28 sorties were made on convoy-escort duties at distances beyond 600 miles, and all used Procedure 'B'. The actual number of meetings was 20. Experience indicated that had W/T homing not been used the expected number of meetings would have been at least 25 per cent less.

[1] Coastal Command File CC/S.9118/8, Part II. [2] C.C. O.R.S. Report No. 220.

The increasing use of very-long-range aircraft underlined the advantages of W/T homing and emphasised the need for its perfection. The percentage of successful W/T homing was remarkably constant up to March 1943, but from April onwards the results were much more satisfactory, due almost entirely to an improvement in W/T communication. Already, between July 1942 and March 1943, aircraft which were successful in establishing W/T contact with their convoys had succeeded in meeting them nine times out of ten. But in April 1943, of 56 sorties on escort to the North Atlantic merchant convoys, of which 52 were ordered to use Procedure 'B', no less than 49 met their convoy, and two of the three which failed to meet did so through being forced to return to base with engine trouble. Significantly, of the four sorties which did not use Procedure 'B', three failed to meet their convoy. W/T homing by Procedure 'B', begun as an emergency measure, came to be used almost invariably by No. 15 Group in the North Atlantic. It substantially increased the percentage of meetings, especially at long range, and enabled escort aircraft to fly straight to their convoy, thus spending the maximum possible time on the vital duties of escort.

In the summer of 1940 a merchant ship especially equipped with radio interception equipment was sent by the Admiralty to investigate U-boat radio emissions in the Atlantic, and as a result a determined drive to equip convoy-escort destroyers with H.F. D/F was begun. Results were not encouraging at first, but gradually, as more was learnt of the new technique, successes became more frequent, and by April 1942 H.F. D/F had become an essential part of the equipment of escort craft.[1] The possibility of loop homing by aircraft on U-boat transmissions was first suggested by the A.O.C.-in-C., Coastal Command in July 1941, when a requirement was stated for H.F. loop homing to take advantage of the transmissions of enemy surface vessels and submarines in the 4 to 14 megacycles per second frequency band.[2] At the Battle of the Atlantic Committee meeting of 21 October 1941 it was suggested that a sub-committee should be formed with representatives of the Admiralty, the Air Ministry, and Headquarters Coastal Command, whose terms of reference would be to keep under review enemy use of radio in the attack on trade, to consider suitable countermeasures, and to make recommendations. Air Ministry approval was given on 18 November, and the first meeting of the Battle of the Atlantic D/F Sub-Committee followed a fortnight later. The meeting considered the types and frequencies of W/T signals made by U-boats and *Focke-Wulf* aircraft, the sequence in which they were made, and their purpose.[3] It was considered that the first signal was likely to be one made on M.F. by a *Focke-Wulf* aircraft homing U-boats to a convoy, followed by its sighting report on H.F. U-boats able to reach the convoy would then report on H.F. the bearing of the *Focke-Wulf* M.F. transmission, and the direction of the signals could be established either by the escort or by the convoy. However, as such signals might emanate from U-boats up to 300 miles or more away, action on them might be wasteful, though a search by air escorts to a limited range would do no harm and might be fruitful. The next indication, a sure and necessary forerunner of a massed U-boat attack, was the U-boats first convoy-sighting report, followed by amplifying reports, all on H.F. The reports provided a fruitful source for direction-finding and subsequent search by surface and air escort, though the problem of reception

[1] Admiralty Files C.B.04050(42)4 and (44)9.
[2] Coastal Command File CC/S.9117/9.
[3] A.M. File CS.9931.

was complicated by the number of frequencies on which the reports might be sent. There usually followed a most promising use of M.F. by the shadowing U-boat, half-hourly transmissions being made to which other U-boats homed. Clearly air and surface escorts could similarly get bearings of the shadowing U-boat, whose range from the convoy would be somewhere near the limit of visibility. A prompt search should therefore result in an attack on the shadower. If the convoy was not successful in shaking off the shadower at this stage, either by attack or by alteration of course at dusk, additional U-boats made contact, and even though their transmissions might be received and homed on, the prospects of a mass attack developing increased rapidly. A study of the whole sequence of the pack-attack control scheme built up by Admiral Doenitz showed that it was of the greatest importance that offensive and evasive action should be taken against the first U-boat in order to prevent a mass attack developing.[1] Employment by the first U-boat of H.F. transmissions to make its reports provided confirmation of the operational requirement raised by the A.O.C.-in-C., Coastal Command in the previous July.

Previous tests with the D/F loop on H.F., which had been carried out by the R.A.E. at the request of the Air Ministry in 1938, had shown that the safe homing range by day was up to 100 miles. Tests beyond this range had been characterised by fading, apparent swinging of bearing, and occasionally by absence of minima.[2] However, a possible range of 100 miles was not discouraging. A tactical instruction on the use of the M.F. transmissions of U-boats was issued by Headquaters Coastal Command on 15 December 1941, and meanwhile the R.A.E. investigated the possibility of modifying existing equipment so that it could be used for loop direction-finding on H.F.[3] The development of new equipment could only have been achieved after prolonged experiments which would possibly be wasted if the enemy made any considerable change in his use of frequencies, and it was in an endeavour to produce quick results that the R.A.E. attempted modifications aimed at making use of the existing facilities in loop design and receiver installation. As a temporary measure, the first tests were carried out with the R.1082 receiver.[4] Although the results were by no means satisfactory they indicated that skilful application would go some way towards solving the problem, and by 1 February 1942 the installation had been made to work reasonably well in a Catalina, the standard Bendix loop being plugged into a special R.1082 instead of into the Bendix radio compass.[5] Experimental work was in hand at the R.A.E. to replace the R.1082 with an adaptor on the Bendix radio compass, and preparations were made for adapting the Marconi R.1155 should it become a firm requirement in Catalina, Liberator and Fortress aircraft, using the Bendix loop and receiver, and in Sunderland, Whitley and Wellington aircraft, using the Marconi loop and receiver. In point of fact, the A.O.C.-in-C., Coastal Command had stated a clear requirement on 5 July 1941, but its complexity and implications were so great that it came to be regarded as a matter for full investigation rather than an immediate operational requirement. By April 1942, six modified R.1082 receivers were in use in Catalina aircraft of Nos. 209 and 210 Squadrons, and development of suitable modifications of Marconi and Bendix equipment was being undertaken by the

[1] Coastal Command File CC/S.9117/9.

[2] A.M. File S.48388.

[3] Coastal Command File CC/S.9117/9: There was never any evidence of success in using the D/F loop on transmissions.

[4] A.M. File CS.9931.

[5] Coastal Command File CC/S.9117/9.

firms of Marconi and Plessey.[1] It was recognised that the proposed extension of employment of radio equipment would demand the services of an additional crew member, and four wireless operator/air gunners were selected and trained in the new technique, one being attached to the R.A.E., two to No. 209 Squadron and one to No. 210 Squadron. They in their turn were to train other crew-members as aircraft were fitted.

At the ninth meeting of the Air/Sea Interception Committee on 9 July 1942, the A.O.C.-in-C., Coastal Command stated that a Catalina fitted with special H.F. D/F equipment had returned to Sullom Voe, and that although no U-boat transmissions had been heard during operations, transmissions had been heard when the aircraft was riding a buoy at Sullom Voe.[2] At that time, only the temporary R.1082 sets had been fitted, and the A.O.C.-in-C. felt that substantial progress must be made by the autumn. In view of the success of shipborne equipment it was decided to hasten development of the airborne sets, and the A.O.C.-in-C., Coastal Command formally confirmed an operational requirement on 18 July 1942. Fifty frequency-changers, styled Type R.1369, were ordered from the firm of Plessey for fitting in conjunction with the Bendix receiver, and the firm of Marconi had been given a development contract for similarly modifying three R.1155 receivers, but little progress had been made. Provisioning action for a further 200 Plessey converters for Catalina, Fortress and Liberator aircraft was taken, and the Marconi development contract was increased from three sets to 50 so that equipment would be available for Sunderlands, Whitleys and Wellingtons.[3]

Delays in production of the equipment continued. The basic difficulty lay in the fact that the natural electric frequency of aircraft wings and fuselages often fell in the frequency bands in which H.F. loop cover was required, producing very great and not always regular and predictable errors. The incoming signal was liable to resonate with the metal structure of the aircraft, producing an effect of transmissions coming from any direction regardless of their true source. This feature necessitated experimental work in the actual types of aircraft to be used operationally, trials on one type of aircraft not necessarily giving any indication of what might happen on another. A further reason for delay was the lack of the necessary plugs and sockets for use with the Bendix equipment; they had been ordered from the United States of America but had not been delivered. There were similar delays with the Marconi equipment.[4] Other pressing problems concerned the training of wireless operators in the operation of the new equipment, and the provision of seating accommodation for an extra crew member, with the additional weight and loss of payload involved.[5] The production delays prompted comment from the Director of Telecommunications, who was particularly concerned that there seemed to be no reserve capacity for small projects which could be of vital importance for a short period. The R.1369 was only a simple frequency-changer, yet the gap between type approval and commencement of delivery was expected to be 30 weeks. The Director of Telecommunications classed the production demand as the sort which arises quickly and sometimes fades away altogether, '. . . but if only apparatus can be made available to deal with the situation quickly it puts us one up on the enemy . . .'[6]

[1] A.M. File CS.9931.
[2] A.M. File CS.9931.
[3] A.M. File CS.15850.
[4] A.M. File CS.15850.
[5] A.M. File CS.15850.
[6] A.M. File CS.17375.

On 3 October 1942, tests were carried out with a Catalina using modified Bendix equipment, and a Sunderland using modified Marconi, in homing to a captured U-boat transmitter installed in H.M.S. *Adrian*, at Holyhead. The tests gave hopeful indications, but failed to shed much light on the performance to be expected in operational conditions. The recorded results referred almost exclusively to homing as opposed to the taking of bearings, and the crucial question remained whether a sufficiently accurate bearing could be taken in the first instance to allow an aircraft to turn on to it with confidence.[1] On 28 October 1942, Headquarters Coastal Command requested the installation of suitably modified R.1155 receivers in Fortresses and Liberators, as the R.A.E. had found it impracticable to fit the R.1369 in these aircraft, and at the same time the requirement for installation in Whitleys and Wellingtons was withdrawn. At the end of the year the R.1369 installation, with the standard loop and Bendix radio compass, had been prototyped, approved and ground and air-tested. 250 R.1369 convertors were being produced, but only three had been delivered. These had been fitted to Catalina aircraft of No. 210 Squadron. For Sunderlands development was being undertaken of a modified R.1155 with a special H.F. loop. Early tests by Coastal Command had been unsatisfactory, and the R.A.E. was carrying out further investigations. A development contract for 50 modified receivers had been placed with the firm of Marconi. At the end of December the Halifax was added to the list of aircraft requiring extended D/F facilities, and it was possible that a Wellington installation might also be required in the future. But by January 1943, eighteen months after statement of the operational requirement, only four aircraft, all Catalinas, had been equipped, apart from those originally equipped as an interim measure with the modified R.1082.[2]

On 27 February 1943, following a review of maintenance, training, and availability within Coastal Command, the A.O.C.-in-C. informed the Air Ministry that he had reluctantly come to the conclusion that the H.F. homing equipment, while desirable, was no longer essential and should therefore be abandoned as an operational requirement. Several factors governed his decision.[3] The weight of the extra crew-member needed to operate the equipment, in addition to the weight of the equipment itself, could only be compensated for by a reduction in fuel with a consequent reduction in aircraft range. Installation and servicing of the additional equipment necessitated a larger establishment of personnel at a time when every effort was being made to conserve manpower. Development of the modified R.1155 was proceeding very slowly, and was a great deal more difficult than had been expected. Aircraft could not be spared from operations to permit installation, trials and modifications to be carried out. The reception of, and homing to, curtailed H.F. transmissions was more difficult than had at first been thought and would necessitate concentrated training in actual operational conditions. The scarcity of occasions when the equipment could be used did not justify its introduction. Ships equipped with better apparatus could pass on to escorting aircraft any information they gained. Final estimated dates for the earliest possible full-scale production of the modifications made it impossible to look forward to general installation in long-range operational aircraft before May 1943.[4] By then the U-boat pack-attack method used in the Atlantic had been decisively

[1] A.M. File CS.8931. [2] A.M. File CS.8931. [3] A.M. File CS.17875.
[4] Coastal Command File CC/S.7010/10/6.

defeated, and the requirement lapsed.[1] The advisibility of leaving direction-finding to escort vessels and relying on them to pass on Intelligence to escorting aircraft had been considered but rejected in February 1942. It was apparent from the start that the provision of suitable equipment would be difficult, but the urgency was great and any addition to the power of aircraft to seek out U-boats was worth while. Nevertheless, due consideration of two factors only, the loss of range of the aircraft and the increased demand for personnel at a time when reserves of manpower were becoming exhausted, might have brought immediate acceptance of the proposal to concentrate on H.F. loop bearings taken by escort craft. However, at the height of the most successful period of the whole U-boat campaign against the Atlantic convoy routes, a useful means of U-boat detection was denied to aircraft of Coastal Command, in spite of the fact that an operational requirement had been declared over one year before the start of the period.

The necessity for some form of homing equipment other than V.H.F. R/T for aircraft of photographic reconnaissance units was first suggested in August 1940, installation of the Fighter Command V.H.F. system TR.1133 in P.R.U. aircraft being unacceptable to Headquarters Coastal Command, owing to the size and weight of the equipment. P.R.U. aircraft had a special need for a homing device in that the heights at which they operated added to the difficulties of accurate wind velocity forecasting. Rebecca was at first suggested, but the Telecommunications Research Establishment suggested as an alternative a simple beacon with a searchlight beam rotating clockwise, to be used in conjunction with a stopwatch and simple receiver in the aircraft; Fleet Air Arm aircraft used the system as an aid to returning to their carriers. The R.A.E. had designed the first receiver, the R.1110, and had recently developed a more advanced set, the R.1147, which was about to be produced in quantity and was expected to be available.[2]

In March 1941 the Admiralty was requested to make available two R.1147 receivers for trial installation in P.R.U. Spitfires. On 29 September 1941 installation of an R.1147 in a P.R.U. Spitfire had been completed by the R.A.E., ground and air tests of the equipment had been carried out, and the range and characteristics obtained were considered by the R.A.E. to be satisfactory for operational use. Retrospective installation in other P.R.U. aircraft was recommended. However, the O.C. No. 1 P.R.U., at whose unit the trials had taken place, thought the recommendations were premature, as the installation was still undergoing tests. A report on the results of further tests was made on 11 October. Successive homing bearings had varied by as much as 10 degrees, and had entailed considerable concentration by the pilot, which would not be possible when he was flying entirely on instruments during operations. Appreciable errors resulted from flying on an incorrect bearing for only a few minutes when letting down at a high groundspeed. Results obtained by a navigator in a Fulmar were far more accurate, partly owing to the lower ground speed, but mainly because of the increased concentration possible by the navigator. Headquarters Coastal Command considered that the object of the installation, to be an aid only in adverse weather, had been overlooked in the report, but the main objection remained that, in adverse conditions,

[1] A.H.B. Narrative 'The R.A.F. in Maritime War'.

[2] Coastal Command File CC/S.9110/46.

concentrating on instruments other than the normal flying instruments was impossible, or at least unwise. Nevertheless, Headquarters Coastal Command recommended that development should be continued and that provision should be made for installation of the equipment in all P.R.U. aircraft and for the installation of the necessary ground beacons. On 27 October it was confirmed that retrospective installation was required in all P.R.U. Spitfires to be followed by installation on aircraft production lines.

However, following further trials of the R.1147, and a trial installation of TR.1133 carried out in a P.R.U. Spitfire by unit personnel, on 16 December 1941 Headquarters Coastal Command requested the suspension of provisioning of the R.1147 until after completion of further TR.1133 trials. They were carried out at Duxford in the same month, after which the O.C. No. 1 P.R.U. reported that there was no difficulty in fitting the installations if the number of oxygen bottles carried was reduced from six to three.[1] On 6 January 1942, all instructions issued regarding the fitting of R.1147 were cancelled. Use of sector V.H.F. homing stations adjacent to photographic reconnaissance units was arranged with Headquarters Fighter Command and P.R.U. aircraft began to use the TR.1133 installation in April 1942, eighteen months after the original requirement had been raised, during which time they had been operated with no radio installation of any kind.[2]

Cathode-Ray D/F Organisation

Shortly after the outbreak of war, it was proposed that Bomber Command aircraft should make use of long-range cathode-ray D/F. It was argued that once aircraft had crossed the German border their presence was known and there was no further object in maintaining W/T silence. At that time two experimental C/R D/F equipments were available for Bomber Command and a further three for Coastal Command, and an order for thirteen more had been placed with the firm of Plessey. Their installation would make possible the provision of five baselines of 10 D/F stations in Bomber Command, and four baselines of eight stations in Coastal Command. Although doubts had been expressed whether the point had been reached where production of the sets was justifiable, the Director of Communications Development, Mr. R. A. Watson Watt, expressed his conviction that the cathode-ray direction-finder would give short and long-range results which could be obtained in no other way, and the order was approved. Negotiations for the acquisition of land for sites were already in progress, and delivery of the equipment was expected in three to four months; although the exact siting in some instances had not been settled, landline arrangements were in hand. It was realised that relatively high-powered transmitters would be required to work aircraft at the ranges envisaged, and although delivery of S.W.B.8.B. transmitters was not expected for twelve months, a satisfactory alternative was found in the Type M.13 transmitter made by the Standard Telephones and Cables Company. Baseline linkage between transmitters was to be maintained by use of the T.1087, and tests of possible frequencies were carried out. In January 1940, sites for 10 C/R D/F stations had been settled, and in April 1940, the firm of Plessey informed the Air Ministry that the first of the C/R D/F equipments had undergone a series of tests and was

[1] There had been no occasion to use more than three bottles during operations.

[2] Coastal Command File CC/S.9110/46.

ready for transporting to the first D/F site.[1] The first three sets were installed at Butser (No. 1 Site), Dyce, and Acklington, range and calibration tests being carried out between 17 and 25 May by a Hampden flying between Upper Heyford, Aldergrove and the Hebrides. Tests were made during day-time on 7820 kilocycles per second, at night on 4077 kilocycles per second, and during the intermediate period on 6758 kilocycles per second; ranges up to 600 miles were obtained on all frequencies. The errors shown on Butser were 0 to 2 degrees, the average error being 1 degree. On Dyce the error was from 0 to 9 degrees, the average being plus 6 degrees. The manufacturers considered that the error at Dyce was large because the station had only just been completed and there had been no time to check it over. On 7 September, as a further trial, an aircraft flew round Dyce on a 25-mile radius over eight known positions, transmitting on a frequency of 6025 kilocycles per second. At one position an error of 6 degrees was recorded, but on all other bearings the maximum error was plus 1·25 degrees.

Listening watches were kept on 4077 kilocycles per second for Bomber Command aircraft by Butser from 4 August 1940 and by Butser and Dyce from 18 September. Acklington also kept watch, but its bearings were not taken into account for the purpose of fixes. Over a period of about two months 730 fixes were requested, but reports made by operational aircraft detailed to request fixes from Butser when actually certain of their position indicated that serious errors were present. An average error of 40 to 50 miles in fixes at a range of 600 miles was reported, but investigation revealed that the report was based on a number of false or doubtful premises. Actual positions of aircraft, for instance, had been shown as 'nearest town', rendering accurate analysis of the results impossible. A representative of Headquarters Bomber Command made a further investigation of Butser in October because large errors were still reported. His findings revealed that Butser, Acklington and Dyce had not been calibrated by an aircraft in flight; the operators at Dyce were inexperienced; the majority of bearings from Dyce were inaccurate; generally bearings from Butser were reliable; whenever bearings from Acklington were applied to those from Butser and Dyce, the error in the fix given by the two stations alone was reduced. Weather conditions during the winter months of 1940/41 restricted the distances at which aircraft had operated, thus reducing the need for cathode-ray D/F, but an attempt was made to assess the accuracy of fixes obtained from the Butser–Dyce section. The total number of fixes given in this period were 232, and of the 58 chosen for analysis, only 44 could be examined because of discrepancies; some of the fixes reported by crews of Bomber Command were not given to any aircraft at the time and on the date stated. The general conclusions drawn were that bearings taken by Butser were twice as accurate as those taken by the other two stations; that all large errors by Dyce and Acklington were positive; that the differences were not confined to any particular region; and that there would be no improvement were Dyce or Acklington to be withdrawn from the system.

[1] 3 at Butser (near Petersfield). Parent station—Gosport.
2 at Perwinnes Moss (near Dyce). Parent station—Aberdeen.
2 at St. Eval.
1 at Widdrington. Parent station—Acklington.
1 at Low Mye (near Stoneykirk). Parent station—West Freugh.
1 at High Three Mark (near Stoneykirk). Parent station—West Freugh.
Arrangements for personnel and administration were the responsibility of parent stations, and gnomonic projection maps were prepared by the Maps Branch.

Meanwhile, the long-range cathode-ray D/F stations allotted to Coastal Command, St. Eval and Stranraer, had also come into operation. St. Eval reported that fixes given to aircraft on the day frequency seemed to be generally of good class; intersections of bearings received at the three stations (Dyce operated with Coastal Command also) were good, and 'cocked hats' were small. No criticisms had been received, but no information was available upon which an assessment of the accuracy of the section might be based. Stranraer reported that no trouble had been experienced; reception was excellent and at distances over 100 miles bearings were accurate. Dyce reported that adjustments made to the aerial feeder system had greatly increased the percentage of first-class bearings and more clearly defined the image on the tube. Heavy interference from aurora borealis had been experienced in March. It was difficult to make recommendations for improvement until information was received about the standard of the existing service.

During the summer of 1941, when Bomber Command operations were confined to targets at short range because of the shorter nights, the Butser section closed, unless specifically requested, but when the service was resumed with the approach of the winter of 1941/42 the reliability of fixes given was again called into question, and in the course of the winter the service was used less and less by Bomber Command aircraft, the advent of radar systems largely removing the need for it.[1] In March 1942 a conference was held at the Air Ministry to decide the future employment of the cathode-ray D/F service, which was no longer required by Bomber Command.[2] It was agreed that, while fixes were liable to be inaccurate, there was no other equivalent radio aid to navigation available to aircraft of Coastal Command and No. 44 Group, and that retention of the service for their use was necessary. No. 44 Group required coverage from Malta over France, from Gibraltar via Cape Finnesterre to Lands End, and over the Newfoundland and Icelandic approaches. Coastal Command required coverage over the Western Approaches and the South-Western Approaches. The main No. 44 Group requirement was for assistance in homing to airfields in the United Kingdom, while Coastal Command required fixing facilities on patrol as a check on D.R. navigation. A common-user service was therefore introduced, with Coastal Command and No. 44 Group as the prime users. Existing equipment was repositioned and additional equipment provided to meet the requirements of the new service, the main repositioning being to Iceland and Northern Ireland.[3] It was by no means certain at first that the new service would continue indefinitely, but by the end of 1942 it had become apparent that for some time to come no alternative organisation could be provided which would meet the requirements of homing and fixing at long ranges. A survey carried out during 1942 by Headquarters No. 26 (Signals) Group, who had been given control of the new organisation, showed that bearings could be placed in different categories from the presentation on the cathode-ray tube, and that the system was capable of accurate and consistent working by day and night in the 3 to 9 megacycles per second frequency band if aircraft were more than 300 miles distant.[4]

The new organisation comprised three D/F sites at Sandgerdi (Iceland), Dyce, Ballywattick (Northern Ireland), and St. Eval, and two at Butser, with a central plotting control room situated at Old Boston (near R.A.F. Blackbrook, between

[1] A.M. File S.46691. [2] A.M. File S.59354. [3] A.M. File S.59354.
[4] A.M. File S.46691.

Liverpool and Manchester). The central plotting room replaced the old area controls at Prestwick (Transatlantic) and Gloucester (Overseas), and the loss of the area control facility at Prestwick for transatlantic aircraft worried Headquarters Transport Command. It was felt that the aim of the new system, involving a central plotting room, was sound, but that there was a danger of delays between aircraft transmissions and the passing of the position by Old Boston.[1] The previous system, whereby T.A.C. Prestwick and O.A.C. Gloucester plotted their own fixes from the individual bearings of the same cathode-ray stations, gave the area controllers facilities upon which they depended for the safe control of aircraft. It was felt that Old Boston was not fulfilling any function which was not better placed in the old area controls, both aircraft and control being robbed of essential requirements by the new system, which was considered clumsy. Tests showed that fixes took much longer to obtain, and that delays between aircraft transmission and the passing of positions under the new system had been up to 50 minutes. Headquarters Coastal Command also reported that the service was most unreliable and erratic, and that it took about 30 to 40 minutes to obtain a fix.[2] However, the advantages of a central control outweighed early minor disadvantages, which were mostly eradicated with experience, and with Old Boston remaining as the control station, the cathode-ray D/F organisation became:—[3]

Black Net. Sandgerdi, Ballywattick, St. Eval and Butser. For Transport Command (North Atlantic route).

Red Net. Sandgerdi, Dyce, Ballywattick, Butser. For Coastal Command.

Blue Net. Ballywattick and Butser. Later a third station at St. Eval was added. For Transport Command.

Green Net. Sandgerdi, Dyce, St. Eval, Ballywattick. Later a station in the Azores was added. For Transport Command.

This organisation remained in force until the end of the war, and with new-type Plessey equipment, R.L. 185, becoming available during 1944/1945, several stations were re-equipped, although installation was suspended after the end of hostilities in Europe. By this time, the service was being used largely for air/sea rescue purposes outside M.F. D/F cover, where there was no other means of obtaining a fix and thus determining a search area for an aircraft which had not been able to pass its position before ditching; the best possible cover of the entire Atlantic area was required for this purpose. For routine navigation, the cathode-ray service was by then rarely used inside Loran cover, although south of 50 degrees north, where there was little Loran cover, it was still the only aid available when astro-navigation could not be used.[4]

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[1] Transport Command O.R.B., October 1943.

[2] A.M. File S.46691, Part II.

[3] Frequencies in kilocycles per second were:—

Black Net	6265
Red Net	6620/4575
Blue Net	8885/4575
Green Net	6800

[4] A separate cathode-ray D/F system for the U.S.A.A.F. was installed in 1944, stations being built at Dyce, Mullaghmore (Northern Ireland), St. Mawgan, Horsham St. Faith, and Meeks Field (Iceland). An interim scheme comprising four temporary stations came into being pending the completion of the full service. The introduction of a special system for the U.S.A.A.F. avoided the overloading of R.A.F. channels.

German Wireless Direction-Finding Systems

The capture of an enemy training school examination paper in navigation enabled deductions to be made as early as September 1940 on the German use of radio. The paper showed that complete reliance was placed on radio navigation, the aircraft D/F loop being used with specially placed and specially selected radio beacons and a conveniently placed broadcasting station. For an operational flight several beacons were selected, one and if possible two between the base and the target, and one well away on the beam of the aircraft, suitably placed for getting a good check on ground-speeds. From this paper and previous Intelligence reports it was clear that the *Luftwaffe* used track and other beacons as a check on ground-speed whenever possible. When it was not possible to use a beacon between the base and the target, aircraft flew on back bearings from two radio beacons, which were kept in line so as to maintain the required track. Bearings were obtained quickly by means of a navigator-operated D/F loop, the expected accuracy being of a high order. All the indications were that German aircraft were continually homing on a beacon or working on tail bearings so as to give a good track, while another station was used to check groundspeed. The navigator was thus chiefly a radio navigator, though he was also expected to be capable of D.R. navigation.[1]

The absorption with beam technology as an aid to navigation, and sometimes as a complete system of navigation, meant that the Germans were particularly susceptible to the effects of radio countermeasures, far more so than a Service in which D/F was regarded as one of several aids.[2] Countermeasures designed to confuse crews flying on a beam were more successful than were the attempts to interfere with the R.A.F. system of two-way communication with D/F ground stations. An instance in which an enemy ground station posed as a British station and attempted to work an R.A.F. aircraft occurred on the night 7/8 May 1941, when an enemy ground station copied the call-sign of Heston M.F. D/F station and attempted to work a British aircraft.[3] The effort was not skilfully conceived, but it showed how readily discrepancies in procedure and a strange method of operating could be recognised by a competent operator. Finding its efforts to work the aircraft unsuccessful, the enemy station called Heston on several occasions, using the aircraft's call-sign, but Heston declined to answer. The radio operator in the aircraft avoided any possibility of error by using the coded challenge each time he requested a fix. This interference was repeated on several subsequent occasions, the enemy station attempting on one occasion to pass incorrect fixes, but all such attempts failed because of incorrect procedure and the style of morse used.

River

By the winter of 1940 the *Luftwaffe* was using a special type of directive beam known as a *River* beam for accurate bombing at night or in conditions of bad visibility. The system consisted of a narrow approach beam which was laid over the target, and two narrow cross-beams which were made to intersect the approach beam at pre-determined points, enabling a precise calculation

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[1] No. 18 Group O.R.B., September 1940.

[2] *See* Royal Air Force Signals History, Volume VII : 'Radio Counter-Measures', for further details.

[3] A.M. File A.891009/46.

to be made of the actual moment of bomb release. The approach beam originated from transmitters situated in the Cherbourg peninsula, the width of the beam varying, according to target distance, between 200 and 400 yards. Only a limited number of German aircraft carried equipment enabling them to use this system, and they were used as pathfinders with the object of fixing the target in order to guide the following aircraft. Pathfinder aircraft belonged to the crack squadrons, and although they might avoid flying in the beam during most of the flight, they were bound to remain rigidly in the narrow cone during the last 20 miles of flight before the target was reached.[1]

Knickebein

The *Knickebein* beams transmitted a much wider ray than the *River* type, and apart from their considerably longer range were similar to the normal *Lorenz* landing beam. As with *River*, the Germans relied on this system to a greater or lesser extent according to the weather and the standard of navigational training of crews. Pilots tended to avoid following the continuous note indication in the centre of the beam for fear of finding fighters and A.A. fire concentrated along it, but they used the beam to check their navigation by occasional reference to the distinctive indications of the bands on either side of the continuous note. They usually used the starboard side of the beam on the outward flight and the port side on the return. Headquarters Fighter Command evolved several systems of using the beams as a guide to interception, and measures were taken to interfere with them to confuse the German crews.[2]

Sonne (Consol)

The *Sonne* or Consol system consisted of a series of M.F. beacons, located along the Atlantic and Mediterranean coastlines, which were capable of providing bearings of high accuracy, and which could be used in pairs to give fixes. They were primarily intended for use by U-boats and long-range reconnaissance aircraft. By suitable switching to three aerials in line a slowly rotating fan-shaped beam, 120 degrees in width, was produced. No extra equipment beyond a simple receiver capable of receiving M.F. transmissions was needed, and the system covered most of the North Sea and large areas of the Atlantic.[3] An aircraft wireless operator tuned in to the beacon signal, which consisted of a number of dots and dashes separated by a steady signal, and noted the number of dots and dashes heard from commencement of the keying cycle. Reference was then made to an appropriate lattice chart and the position line selected. Accuracy by day was plus or minus 0·3 degrees up to a maximum error of plus or minus one degree, propagation being due almost exclusively to the groundwave, providing very stable conditions. Bearings could be obtained at ranges up to 1,000 to 1,500 miles. Accuracy decreased as distance increased because as the field strength became less the liability to interference increased. At night the situation was essentially different because of the appearance of the skywave; a systematic displacement in the main beam pattern of radiation was capable of causing errors up to two degrees, but a correction for this displacement could be applied. However, scatter,

[1] No. 9 Group O.R.B., December 1940.

[2] *See* Royal Air Force Signals History, Volume VII: 'Radio Counter-Measures'.

[3] Coastal Command Signals Review, Volume 2, No. 7, July 1945.

ranging from plus or minus one to three degrees, although capable of being anticipated, was responsible for random deviation at night which could not be forecast.[1]

Great assistance was rendered to Coastal Command aircraft and later Transport Command aircraft by the *Sonne* beacon system, known to the R.A.F. as Consol, and it was estimated that in Coastal Command one fifth of all radio navigational assistance was obtained from this source.[2] Indeed, in 1944, when the Allied armies began to overrun the Continent, all possible measures were taken to ensure the continued operation of the *Sonne* system, but the difficulty was that whenever an area in which a *Sonne* beacon was situated was threatened with capture, the enemy naturally dismantled and removed or destroyed the equipment. The success of the Allied armies thus constituted an involuntary threat to the safety of Allied aircraft. The development of a British equivalent of *Sonne* was begun in November 1944, but no great progress was made up to the end of the war.[3]

Komet

In the course of long-range operations over the western Atlantic, the enemy raised a requirement for an accurate radio navigational aid with a range of at least 3,000 kilometres, and since beam technology had already been highly developed in Germany, it was natural to attempt to meet the requirement by the use of the beam principle. The *Sonne* system was already available for radio navigation for distances up to about 1,500 kilometres, and it was proposed to develop a similar system in the short-wave band, reaching ranges of between 2,000 and 4,000 kilometres by a choice of suitable wavelengths. It was thought that by constructing two installations, one in the south of France at Bordeaux and one in Denmark at Kolbi, it would be possible to obtain fixes in long-range aircraft over the entire Atlantic operational area. Up to the middle of 1944, however, trials with *Komet* were unsatisfactory, attempts to produce a beam concentration of adequate width proving unsuccessful. By this time, German long-range operations in the Atlantic had ceased and development of *Komet* was abandoned.[4]

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[1] Air Scientific Intelligence Technical Translation No. 14.
[2] Coastal Command O.R.B., 1944.
[3] Coastal Command File CC/S.7512/7/4.
[4] A.I. 12/USAFE/TE 35.

CHAPTER 22

WIRELESS DIRECTION-FINDING IN OVERSEAS COMMANDS 1939-1945

Wireless direction-finding systems were required to fulfil two functions in overseas commands; aids to navigation in operational theatres, and aids to navigation along aircraft reinforcement routes. The systems provided for operational theatres followed, in the main, the familiar pattern of those provided for operational commands based in the United Kingdom, but retained their importance until a later stage in the war because radar systems were not so readily available and in some instances were unsuitable. In no sphere of wartime flying was wireless direction-finding more widely used or of greater value than in the reinforcement flight organisation.

The outstanding requirement for direction-finding stations overseas was decided in July 1938 as six H.F. and five M.F. in the Far East, two mobile H.F. and two mobile M.F. in Egypt, two M.F. at Malta, one H.F. and one M.F. at Aden, one H.F. at Nairobi, and possibly one M.F. in Palestine. By the outbreak of war the only installations to have been completed were the M.F. stations in Malta and Egypt. Delivery of the remainder of the equipment was postponed in case it should be more urgently required in the United Kingdom.

The Far East 1939 to 1942

The chief requirement for D/F in Malaya, as envisaged before the war, was to fix the position of aircraft on reconnaissance patrols at distances likely to extend appreciably beyond 100 miles from Singapore Island.[1] It was known that the range and accuracy of M.F. D/F varied greatly in this area because of atmospherics, and that the normal operational range was about 100 miles (civil M.F. stations had been operating in the Far East for some years). While more modern M.F. stations might give better ranges, perhaps up to 150 miles, still greater ranges were wanted, and it was in an attempt to solve this problem of range that the provision of H.F. D/F stations was suggested, whilst the M.F. stations were to be used for homing. This was in complete contrast to the roles allotted to H.F. and M.F. systems in the United Kingdom, where H.F. was used for homing and M.F. for long-range fixing. The object in the Far East was to use H.F. beyond the skip areas, which normally extended from about 100 to 250 miles, as the effects of atmospherics were less on higher frequencies. The stations would still be made use of for short-range homing, supplemented by M.F. for short-range fixing and homing.

At the beginning of 1938 the only D/F stations in existence in Malaya were the civil M.F. stations at Singapore and Penang although an R.A.F. M.F. station was in the process of erection at Seletar. There was, however, a plan in existence for the provision of Service H.F. and M.F. stations at Tengah, Jesselton and Kuching (south-western Sarawak). A station was to be provided at Tengah by transferring the existing M.F. station from Seletar. Headquarters

[1] A.M. File S.45161.

Far East Command was by no means satisfied with the plan, and in March 1938 its limitations were brought to the notice of the Air Ministry.[1] The requirement, it was considered, was for the allotment of a second operational frequency and the erection of further suitable D/F stations. It was recommended that the Singapore reconnaissance area should be divided into two zones, each with a local operational frequency. D/F stations would be required at Tengah and Jesselton (British North Borneo) for the Northern Zone, and at Tengah, Kuching and either Kuantan or Sungei Patani for the Southern Zone. The Air Ministry made the following counter-proposals :—

Northern Zone. H.F. D/F stations at Tengah, Jesselton and Kuching.

Southern Zone. M.F. D/F stations at Tengah, Kuching and Kuantan, with use of an H.F. D/F station at Sungei Patani to combine with Jesselton in periods of bad M.F. reception.

It was thought that, if H.F. was used in the Southern Zone, difficulties would be encountered over a large part of the area because of skip effects. If M.F. was used, a fairly large proportion of the area would be covered, but since there was always the possibility that atmospherics might render the M.F. system inoperative just when it was most wanted, an H.F. D/F station could be sited at Sungei Patani, where D/F facilities would presumably be wanted in any event as squadrons were to be based there. When atmospheric conditions precluded the use of M.F., the northern area station at Jesselton could combine with Sungei Patani to cover the southern area, leaving the two remaining stations at Tengah and Kuching to cover the northern area. Normally, when Sungei Patani H.F. D/F was not required by the Southern Zone, it could be used as a homing and safety service for its own aircraft. Summarised, the Air Ministry proposals were :—

(*a*) H.F. D/F and M.F. D/F at Tengah and Kuching.

(*b*) H.F. D/F only at Jesselton and Sungei Patani.

(*c*) M.F. D/F only at Kuantan.

The possibility of extending the area covered by D/F by making use of French facilities on the south coast of Indo-China was considered at the Air Ministry, and as a result Headquarters Far East Command was urged to co-operate locally with the French authorities. But as far as was known in Singapore, there were no H.F. stations in French Indo-China, and no M.F. stations south of latitude 18 degrees.[2] Also, before any proposals were made to the French Indo-China authorities by Headquarters Far East Command for the use of D/F facilities, preliminary action at the appropriate level was essential, together with instructions on the scope of any such negotiations. No such preliminary action was taken and no approach to the French authorities in Indo-China was in fact made.

For a number of reasons the plan approved by the Air Ministry underwent many changes ; it underwent contraction due to the demands of other theatres of war, particularly of the United Kingdom after the outbreak of war in Europe, and expansion as a result of the planned transfer to Malaya of further squadrons. On 24 October 1938 Miri (Sarawak) was substituted for Jesselton, but was later deleted without any site being suggested in its place. A decision not to site the Singapore M.F. D/F station at Tengah was taken in April 1939, an alternative site at Sembawang having been proposed. M.F. D/F for homing

[1] A.M. File S.45130.

[2] A.M. File S.45130.

at Mergui, on the reinforcement route to Singapore between Bangkok and Victoria Point, was agreed in April 1939 but cancelled later, civil M.F. stations at Bangkok, 140 miles to the north, and Victoria Point 170 miles to the south, being left to meet the requirement. The revised plan at the outbreak of war in Europe was:—

H.F. D/F. Tengah, Kuching, Sungei Patani.

M.F. D/F. Singapore (site undecided), Kuching, Kuantan.

There were two other areas in the Far East where further D/F facilities were planned—Ceylon and Burma. In Ceylon, an H.F. and an M.F. station were planned for Trincomalee, and in Burma, an H.F. station was planned for Rangoon, where a civil M.F. station already existed.[1]

Immediately on the outbreak of war in Europe, M.F. D/F equipment earmarked for despatch to the Far East for the stations at Kuching, Kuantan, Mergui (not then cancelled) and Trincomalee, and H.F. equipment earmarked for Sungei Patani and Rangoon, was held back lest it should be more urgently needed in the United Kingdom. H.F. D/F equipment for Tengah, Kuching and Trincomalee had already been sent. On 22 September 1939, arrangements were made between the Air Ministry and Headquarters Far East Command for work to be started on H.F. D/F buildings at Tengah and Kuching directly a Marconi engineer arrived. He left the U.K. in November 1939, his brief being to complete the planned H.F. and M.F. stations at Trincomalee as first priority.[2] The M.F. equipment earmarked for Trincomalee and previously held back was despatched to Ceylon in the same month. Then Tengah and Kuching H.F. stations were to be completed in that order. The engineer arrived at Trincomalee on 24 November 1939, but found that very little progress had been made in anticipation of his visit, and that the site had not yet been cleared of jungle.[3] The delay in clearing the site was due to a misunderstanding, Headquarters No. 222 Group assuming that the site would be chosen by the Marconi engineer on arrival, and that no jungle clearing could therefore be begun meanwhile. By April 1940, jungle clearing had been completed and buildings were ready for the installation of apparatus, but remote control cable was not yet available and calibration could not begin until the cable was laid. Meanwhile, the Marconi engineer left for Malaya.

By the end of April 1940, specifications for the H.F. D/F station at Kuching were ready for despatch, and building was about to start at Tengah. The requirement for an M.F. station at Kuching had been cancelled in October 1939, as with the limited resources available in the Far East at that time, it was not possible to operate aircraft from Sarawak, and the station had been required largely for homing from the areas of H.F. skip. M.F. equipment for Kuantan was not despatched to the Far East until September 1940, as the airfield itself would not be ready until the end of 1941, and immediate provision was not therefore necessary. The H.F. station at Sungei Patani was no longer considered to be necessary, but at the request of Headquarters Far East Command its transfer to Alor Star was agreed in view of the planned increase in air forces in the Far East and the advisibility of a station in northern Malaya for the use of aircraft engaged on seaward reconnaissance.[4] Additional commitments were the provision of H.F. D/F at Seletar, to be installed on the M.F. D/F site when vacated, and at the new headquarters location at Bukit Timah.

[1] The Rangoon project was cancelled in September 1940.
[2] A.M. File S.45161.
[3] A.M. File S.45130.
[4] A.M. File S.45161.

By July 1940, all internal work on the Trincomalee sites had been completed, the masts had been erected, and there was a prospect of the station being in working order within a short time.[1] Both the H.F. and M.F. sites were completed and awaiting transmitting facilities by September, and all that remained was the actual installation of D/F equipment. The Marconi engineer was expected in January 1941, as soon as he had finished at Kuching. However, a serious setback was encountered in the shape of damaged feeder cable. Replacement cable was not received from the United Kingdom until October 1941; one reason for the long delay in its despatch was departmental confusion at the Air Ministry. Meanwhile, early in 1941, the Marconi engineer had decided, in view of the delay in obtaining the replacement cable, to complete the stations at Kuching, Kuantan, and possibly Alor Star, before proceeding to Trincomalee. He had already completed Tengah. The land at Tengah was not acquired until March 1940, and building commenced in May. By the end of June, it was expected that the buildings would be ready for occupation in four to six weeks. The first delay was caused by the contractor sloping the drains the wrong way, rains resulting in flooding. There were subsequent delays due to difficulties in the installation of the air-conditioning plant, but the station was working in October 1940 and calibration was completed by December.[2] By the end of June 1940 a contract for clearing the Kuching site and for the erection of buildings had been let, but due to the slowness of the contractor, building was not completed until February 1941. The equipment had not been installed, and no power supply was available. Power plant was not sent from Singapore until March 1941, and air-conditioning had then to be installed. The engineer was at Kuching in June 1941 supervising the installation of power plant, and the station opened shortly afterwards, but early results were not satisfactory and he had to visit it again later. By early 1941, building of the Kuantan M.F. D/F station was completed, power and control cables installed, and work was about to start on the erection of masts. This work was completed by the end of June, and the station was calibrated in October 1941.[3] Early siting difficulties were encountered at Alor Star but the land had been gazetted for purchase and building was about to start by December 1940, and the foundations had been completed and equipment installed by February 1941. Later, progress was delayed through works difficulties and the non-availability of earth plates, and this and other difficulties accounted for about eight months delay.[4] The installation of D/F equipment was completed in about October/November 1941, but so far as is known the station never operated.[5]

The installation of H.F. D/F at Trincomalee, Tengah, Kuching and Alor Star, and M.F. D/F at Trincomalee and Kuantan, completed the original brief, Alor Star having been substituted for Sungei Patani. Meanwhile, however, four other D/F commitments had arisen during the period, the transfer of Singapore M.F. station from Seletar to Sembawang, the installation of H.F. D/F at Seletar on the old M.F. site, the installation of H.F. D/F at Bukit Timah, and provision of an additional M.F. D/F station to serve Malacokjy. The erection of the H.F. D/F station at Bukit Timah was successfully completed by May 1941, but the Seletar M.F. station was still operating in September 1941, and so far as is known work on the H.F. D/F station at Seletar and the

[1] A.M. File S.45130.
[2] A.M. File S.45161.
[3] A.M. File S.45130.
[4] A.M. File S.45130.
[5] Narrator's interview with Wg. Cdr. T. R. Knight.

transfer of the M.F. station to Sembawang was never begun. The additional M.F. station to serve Malacokjy, with a suggested site at Machang, was proposed by Headquarters Far East Command on 25 September 1941 and subsequently agreed by the Air Ministry. A suitable site at Machang was selected in October 1941, but work was never begun. In March 1941, four transportable DFG. 12 sets were sent to the Far East to form the basis of an H.F. fixer service for fighters at Singapore.[1] Another new facility was the installation of an M.F. beacon, which came into operation at Singapore early in 1942, on a frequency of 1500 kilocycles per second.

Thus, after two years, only the H.F. station at Tengah and the M.F. station at Kuantan had been completed satisfactorily. The reasons for delay were innumerable. The role of the Marconi engineer was misunderstood; headquarters of commands abroad considered that he was to choose sites, and to supervise installation, and that any work undertaken in the clearing of jungle before his arrival might be wasted. This reasoning did not take into account the time taken to purchase land, let contracts, clear jungle, erect buildings, lay cable and provide supply services. Secondly, there was a serious shortage of supervisory signals staff; local contractors in overseas commands often needed far more supervision than was necessary in the United Kingdom.[2] Thirdly, the great distances between each site caused delays in transit. Nevertheless, the direction-finding organisation for the Far East was very nearly completed by the outbreak of the Japanese war, and possibly would have been completed but for the long delays in Trincomalee.

The Middle East

At the outbreak of war R.A.F. Bellini-Tosi M.F. stations were in operation at Heliopolis and Amman, and the Egyptian government operated Adcock M.F. stations at Mersa Matruh, Alexandria and the Dakhla Oasis.[3] There was also an Adcock M.F. station at Lydda, Palestine. There were, however, no H.F. D/F stations or M.F. beacons, and the shortage of R.A.F. wireless operators was such that squadrons were manned on the basis of one wireless operator per flight, until reinforcements were sent to Egypt from Palestine and Trans-Jordan, and from the United Kingdom.[4] With the entry of Italy into the war in June 1940, the need for improved D/F facilities became urgent, and a number of Marconi DFG. 12 equipments were sent to the Middle East. However, during the early months of the desert war radio navigational assistance was limited to the existing M.F. systems, and the stations were not worked until aircraft had crossed the enemy lines on the return flight. W/T silence was imposed except in emergency, and because only a few D/F stations were available all aircraft were expected to limit requests for D/F assistance to a minimum. In the Mediterranean area two M.F. D/F stations and an M.F. beacon were available at Malta, and two Greek Airgonio stations were available at Phaleron, one H.F. and one M.F.

The first three H.F. D/F stations installed in Egypt were sited at Maaten Bagush, Ismailia and Amiriya, the last-named operating R/T for fighters only: they began operating in November 1940.[5] In the same month, a system of M.F.

[1] A.M. File S.45180.
[2] Narrator's interview with Wg. Cdr. T. R. Knight.
[3] R.A.F. Middle East O.R.B. Signals Appendices, August 1939.
[4] R.A.F. M.E. O.R.B. Signals Appendices, August 1939.
[5] R.A.F. M.E. O.R.B. Signals Appendices, November 1940.

beacons was put into operation. The beacons were situated at Maaten Bagush, Amiriya, Ismailia, Fuka and Heliopolis, and were organised to a schedule so that each beacon operated for not less than two five-minute periods per hour, with changes of call-sign every eight hours. The direction-finding organisation was still inadequate, however, and with the arrival of new equipment, many changes and additions were made to it in 1941. Combined with the shortage of equipment was the difficulty of constantly keeping pace with advances and retreats in the various campaigns.[1] In March 1941, Benina (Benghazi) was acting as H.F. D/F control with stations at El Adem, Mersa Matruh, Kabrit and Heraklion (Crete). The M.F. D/F organisation was then Heliopolis, Dekheila (Alexandria) and Eleeniko (Athens). A plan existed for the provision of further H.F. D/F stations in Greece and Crete but had not been implemented by the time of the withdrawal. The M.F. beacon organisation was extended in the same month, and in April 1941 three H.F. D/F stations were allocated to each of five fighter sectors, Heliopolis, Fayid, Port Said, Amiriya, and Haifa, the latter to assist with the air defence of Syria, Cyprus and Palestine. In July 1941 a sixth sector was added at Alexandria. The H.F. D/F organisation for bomber aircraft was changed in April 1941 as a result of the fall of Benghazi and El Adem, a station being re-established at Maaten Bagush. In June 1941 an H.F. D/F station began operating at Heliopolis. In spite of the improvements in overall D/F facilities, experience showed that a short-range navigational aid for homing to desert landing grounds was required, and to meet this requirement 30 Wellesley aircraft D/F loops were allocated for use with squadron pack-sets (T.1083/ R.1082) to provide bearings and homing transmissions at all landing grounds.[2] The loops were all installed and working by September 1941.

From the start of the Cyrenaica campaign in September 1940 to the end of the Greek campaign in April/May 1941, the standard of operating was fairly high, but with the influx of newly trained operators, both as replacements and reinforcements, whose training had necessarily been reduced to a minimum, the standard deteriorated and soon became extremely low.[3] Aircraft were lost owing to the failure of aircrews to take advantage of the D/F aids to navigation provided, and to the inability of operators even to establish communication with their ground control stations.[4] The need was for signals leaders who could exercise disciplinary control and take over training programmes and signals briefing, and their establishment was requested. Meanwhile a programme of intense training for wireless operators was instituted. All operators were subjected to a full-scale test, and were employed for ten hours per month on W/T point-to-point watches at ground stations. Those who fell short of the required standard were attached to the school at Ismailia for refresher courses. Regular training programmes were thereafter carried out on all squadrons. An air/sea rescue organisation was brought into force in July 1941, consisting at first of two Wellingtons, with two launches, at Aboukir, Mersa Matruh and Port Said.[5] Each launch was equipped with a D/F loop. Aircrews were instructed to try to make transmissions on 294 kilocycles per second if forced

[1] R.A.F. M.E. O.R.B. Signals Appendices, January 1942.

[2] R.A.F. M.E. O.R.B. Signals Appendices, April 1941.

[3] R.A.F. M.E. O.R.B. Signals Appendices, September 1941.

[4] R.A.F. M.E. O.R.B. Signals Appendices, June 1941.

[5] R.A.F. M.E. O.R.B. Signals Appendices, July 1941.

down in the sea, to enable rescue launches to home to them. Rescue aircraft also made transmissions on 284 kilocycles per second to home launches to located aircraft. The service was greatly expanded during later campaigns.

The prime lesson of the early campaigns in the Western Desert was the importance of mobility; it was absolutely vital that W/T and D/F equipment should be readily transportable. Much equipment was damaged whilst being moved over rough desert tracks, and the importance of W/T and power vehicles being prime movers was stressed.[1] A suitable layout for vehicles was therefore designed and equipment was installed in them at base depots. Experience was gained in the method of control of aircraft in operations; each bomber group or wing needed and was given its own operational D/F station so that it could control its own aircraft until they were within 50 miles of the landing ground on the return flight. Responsibility was then handed over to squadron ground personnel, who used the pack-sets and portable loop. The vast superiority of Bendix and Marconi equipment over the R.1082/T.1083 was noted, and fighter pilots particularly were finding their wireless equipment inadequate, the combination of TR.9 and T.1087 being incapable of providing the R/T ranges required in mobile warfare.[2] Retrospective fitting of V.H.F. equipment did not begin until 1942, but by May of that year more and more areas and squadrons were changing over.[3] Supplies of ground equipment continued to arrive steadily, and three V.H.F. D/F fixer stations were operating by September 1942 at each of Haifa, Gaza, Port Said, El Arish, Shandur, Heliopolis and Alexandria sectors. Ground equipment was also being installed at Fayoum, Hurghada and Cyprus, and equipment was loaned to the Abadan and Shaibah areas in case they should be reinforced with V.H.F. R/T-fitted aircraft. In addition, a fighter group in the Western Desert was completely fitted with V.H.F. ground equipment. The aircraft equipment position was not so satisfactory, but, by the time of the attack at El Alamein, ten day and two night fighter squadrons had been fitted, seven of the day squadrons operating in the Western Desert.

On 18 October 1942, five days before the start of the El Alamein break-out, Headquarters R.A.F. Middle East outlined a signal plan based on the assumption that the enemy would be routed, and that Allied forces would be established as far west as Tripoli.[4] Staging posts were planned for Mersa Matruh, El Adem, and Benghazi, with H.F. D/F stations and M.F. beacons; and V.H.F. D/F for triangulation at fighter sectors was planned for the Mersa Matruh area, the Tobruk area, the Martuba area, and the Benghazi area. Later a further reinforcement staging post was established at Magrun, with H.F. D/F, V.H.F. D/F, and an M.F. beacon. The formulation of complete and detailed plans for navigational aid for an advancing air force before the advance had begun was an innovation in mobile warfare. The same planning technique was used again in January 1943, when plans were laid for the delivery of a further blow to the retreating Axis forces in North Africa, the objective being the establishment of Allied forces in Tripoli. Staging posts with H.F. D/F and M.F. beacons were planned for Marble Arch and Tripoli, with fighter sectors and V.H.F. D/F at Misurata and Tripoli. The taking-over of the civil M.F. station at Castel Benito

[1] R.A.F. M.E. O.R.B. Signals Appendices, October 1941.
[2] R.A.F. M.E. O.R.B. Signals Appendices, May 1942.
[3] R.A.F. M.E. O.R.B Signals Appendices, May 1942.
[4] R.A.F. M.E. O.R.B. Signals Appendices, October 1942.

was also planned. These stations and many others were established in the course of the defeat of the enemy in North Africa. Radio ranges were established at Tripoli, Benghazi, Cairo, Habbaniyah, Abadan and Sharjah by the end of 1943. Operational training units were transferred to the Middle East from East Africa, and navigational aids were provided for them. In the eastern Mediterranean, H.F. D/F was established at Aleppo (Syria), Lydda (Palestine) and Nicosia (Cyprus), and an M.F. D/F service was also made available.

By the time of Operation Husky, and the subsequent invasion of Italy, the advances made in radar technique had been applied to the requirements of seaborne and airborne invasion, and for the amphibious assault against the Italian mainland, mounted from North Africa and Sicily. A.I. and A.S.V. beacons were installed on the islands of Ustica and Salina, and the Rebecca/Eureka system was employed to assist troop carriers in finding dropping zones. Fighter cover was mounted from airfields in Sicily, where V.H.F. D/F was available, and fighter directing ships equipped with V.H.F. D/F provided close control. H.F. D/F installations and M.F. beacons were provided in Sicily for the use of bombers, and in addition an extensive D/F organisation in North Africa and the eastern Mediterranean was available to aircraft of longer range. Although radar aids were introduced into the Middle East theatre of war, the continuing value of wireless direction-finding may be gauged from the extremely congested state of the Transport Command short-range guard frequencies even in 1944.[1] This reached such a point that operators were urged to make use wherever possible of navigational aids which did not involve transmission by aircraft. In addition, congestion on medium-frequencies caused by the number of beacon and radio range installations was such that it became necessary to stipulate that a frequency spacing of at least 10 kilocycles per second had to be maintained between beacons and ranges less than 1,000 miles apart, and of at least 20 kilocycles per second between beacons and ranges at the same location. In spite of the increased use of radar operationally, the basic navigational aids on transport and reinforcement routes continued to be H.F. D/F, V.H.F. D/F and M.F. beacons, and they were still extensively used by bomber and G.R. aircraft.

East Africa and Aden

In the East Africa Campaign of 1940/41, in which the Italian forces in Eritrea were contained and defeated, wireless direction-finding did not play a significant part. The only available radio aid to navigation was civil M.F. D/F, and this was little used, partly because many aircraft taking part in the campaign were not equipped with wireless or wireless operators, and partly because the nature of operations did not call for long-distance navigational assistance. But by 1942, following the entry of Japan into the war and the threat to Allied shipping in the Indian Ocean from German, Italian and Japanese submarines, Air Headquarters East Africa was formed in Nairobi, and a system of wireless direction-finding for G.R. and fighter aircraft operating within the East African area was planned in May 1942.[2] The existing civil M.F. organisation was inadequate for the scope of operations planned. The area of operational command was Kenya, Uganda, Abyssinia, Tanganyika and Northern Rhodesia on land, and seawards, eastwards as far as 60 degrees east north of the equator and 65 degrees east

[1] R.A.F. M.E. O.R.B. Signals Appendices, July 1944.

[2] R.A.F. M.E. O.R.B. Signals Appendices, May 1942.

south of the equator, northwards as far as 10 degrees north, and southwards as far as the operational range of aircraft permitted. The area of responsibility linked up with that of Aden Command in the north, while in the south, the neutral strip of Portuguese East African coastline separated it from bases in South Africa. The occupation of Madagascar in 1942 provided useful bases to the south-east, while to the extreme east was the reconnaissance area of No. 222 Group with headquarters at Colombo. The size of the area and the type of operations envisaged called for the maximum D/F coverage. The need was for the erection of H.F. D/F stations along the East African coast, in Madagascar, Mauritius and Seychelles, and on one or more of the islands between Madagascar and the mainland; the erection of M/F beacons; and the utilisation of civil M.F. facilities, both British and French.

Permanent reconnaissance bases were established at Mombasa, Dar-Es-Salaam, Diego Suarez, and Mauritius, including H.F. D/F, M.F. D/F (already in existence at all except Diego Suarez), M.F. beacons, and A.S.V. responder beacons. Temporary reconnaissance bases were established at Pamanzi, Seychelles, and Tulear, with M.F. and responder beacons, and H.F. D/F at Seychelles and Tulear. Advanced bases were established at Mogadishu and Lindi, also with H.F. D/F and M.F. and responder beacons, and a detachment was based at Rodriguez with an M.F. beacon. Flying-boat bases with full D/F facilities were established at Kisumu, Diego Suarez and Durban, and Fleet Air Arm bases were opened at Tanga, Plaisance (Mauritius), McKinnon Road, Voi and Andrakaka (Diego Suarez). Fighter sector facilities, on a care and maintenance basis, were provided at Mombasa and Diego Suarez. Considerable use was made of W/T equipment under French ownership in Madagascar, particularly of the M.F. transmitters, used as beacons, at Tulear, Diego Suarez and Tananarive, which had a range of 1,000 miles or more.[1]

The provision of these aids to navigation took place gradually, the first H.F. D/F stations being calibrated in April 1943. By November 1943, an H.F. fixer organisation for aircraft flying over the sea in the East African area included control stations at Mombasa and Diego Suarez, assisted by the stations at Dar-Es-Salaam and Seychelles. By February 1944 the stations at Mauritius, Lindi, Mogadishu and Tulear were ready to join this organisation, which was completed by the addition of Scuiscuiban, a station in British Somaliland under the operational control of Aden.[2] It was eighteen months before the first signals plan of May 1942 was translated into a signals service, but by the beginning of 1944 the D/F facilities in East Africa were on a par with those in other theatres.[3]

Air transport services in East Africa consisted largely of aircraft passing through *en route* to Egypt and South Africa. Traffic was considerable, U.S.A.A.F., S.A.A.F., B.O.A.C., Belgian and French aircraft all operating services, but as late as 1944 such services were still dependent on the civil M.F. organisation for direction-finding assistance, and it was not until mid-1945 that a Transport Command area control system, located at Nairobi, began operating.[4]

[1] A.H.Q. East Africa O.R.B. Appendices, April 1943. Because of the nature of the terrain the French authorities in Madagascar made considerable use of W/T for the internal communications system of the island.

[2] A.S.V. was also widely used for navigation, in conjunction with responder beacons.

[3] A.H.Q. East Africa O.R.B. Appendices, February 1944.

[4] R.A.F. M.E. O.R.B. Signals Appendices, 1944. Another commitment in East Africa was the provision of H.F. D/F, M.F. D/F and M.F. beacons for No. 72 O.T.U. Nanyuki and No. 70 O.T.U. Nakuru, until 1943.

In addition to being an important staging post Aden was the centre of a G.R. organisation complementary to that of East Africa, with an area covering the northern Indian Ocean. The provision of direction-finding stations was planned in 1938 and completed in January 1941.[1] H.F. D/F was installed at Aden, Riyan, Salalah, Bandar Kassim, Socotra, Scuisculban and Masirah.[2] Siting of some of the stations had been carried out with little knowledge of technical requirements, and errors varied from 8 to 16 degrees. The stations at Salalah, Masirah and Riyan were categorised in August 1944 as good, that at Bandar Kassim as fair, and Scuisculban as poor, mainly owing to the proximity of other electrical plant, necessitating re-siting. The G.R. organisation at Aden was reduced in 1945.

India

Pre-war plans for the provision of wireless direction-finding stations in the Far East did not include India; Ceylon and Burma were the nearest areas in which equipment was to be installed. Early in 1942 it became apparent that provision on a large scale was required, since, after the retreat from Burma, it was possible that India might be the next battlefield in the war against Japan. The existing signals facilities, including a civil M.F. D/F service spread thinly over India, were hastily conscripted to aid communication and navigation, and an organisation designed to pool resources was formed.[3] The first need was for an early warning system to cover Bengal, and particularly Calcutta, and V.H.F. D/F was needed for the triangulation of fighters.[4] There was a similar urgent need for early warning and V.H.F. D/F in Ceylon. The development of V.H.F. facilities was, however, slow due to lack of equipment, and in the Bengal area three civil D/F stations were pressed into service as fighter fixer stations, and a further three such stations constituted the sole air-to-ground organisation for bomber and G.R. aircraft in the eastern area.[5] Because of the difficulty of obtaining either ground or aircraft equipment from the European theatre of operations, squadrons operating in Bengal and Burma were still without V.H.F. equipment at the beginning of 1943, except in the Calcutta area, where it was in use by the end of 1942. The fighter effort in the Bengal-Assam area was considerably impaired during this period by the lack of V.H.F. D/F facilities. The operational use of V.H.F. D/F was begun in eastern Bengal in May 1943, and in Ceylon in August 1943.[6]

Operational groups under the control of Air Headquarters India were No. 222 Group with headquarters at Colombo, No. 223 Group on the North-West Frontier and No. 225 Group with headquarters at Bangalore.[7] There were no D/F facilities at first in Ceylon, but an M.F. D/F station was nearly ready at China Bay, and H.F. D/F was in preparation. By February 1944, the G.R. fixing organisation for the Colombo area included H.F. D/F at Diego Garcia, Addu Attoll, Kelai, Koggala, Sigiriya, Trichinopoly, China Bay, and Cochin.[8] Two of the stations, Trichinopoly and China Bay, also operated in the Madras G.R.

[1] A.M. File S.45161.
[2] A.H.Q. East Africa O.R.B. Appendices, February 1944.
[3] Transport Command O.R.B. Signals Appendices, March 1944. The U.S.A.A.F. was at first included but later decided not to participate.
[4] A.H.B./IIJ/50/47/20.
[5] Transport Command O.R.B. Signals Appendices, March 1944.
[6] A.H.B./IIJ/50/47/49.
[7] No. 222 Group O.R.B., September 1941.
[8] A.H.Q. East Africa O.R.B. Appendices, February 1944.

area with Cholavaram, Vizagapatam, and Gannavaram. Three H.F. D/F stations were provided for No. 223 Group, and all groups by that time had been provided with adequate V.H.F. D/F facilities. Under the control of Air Headquarters Bengal were two operational groups; Headquarters No. 221 Group, Calcutta, controlled all offensive and defensive squadrons based in western Bengal, and Headquarters No. 224 Group, Chittagong, controlled all offensive and defensive squadrons along the entire Burma front from north-east Assam to the Mayu Peninsula. The headquarters controlled a G.R. fixing organisation with H.F. D/F stations at Cuttack, Calcutta, Vizagapatam, Chittagong, and Berhampur, and a group of H.F. D/F stations, to cover bomber operations, were installed at Fenni, Comilla, Agartala, Chittagong and Jessore by the end of 1942.[1] V.H.F. homer and fixer systems were established and in use in the operational areas of Bengal and Burma by the end of 1943.

The building up of a system of wireless aids to navigation in A.C.S.E.A. was a slow process, and although by the end of 1943 fairly comprehensive H.F. D/F, M.F. D/F and V.H.F. D/F systems were in existence, they never reached the standard of similar systems in the United Kingdom. Bearings obtained on H.F. and M.F. were apt to be unreliable at night.[2] Experience in meteorological forecasting in this area was almost negligible. Static interference on M.F. rendered it useless for D/F during the monsoon period, and the comparative freedom from static of V.H.F. made its speedy introduction of vital importance.[3] Navigation and blind bombing radar systems, not available until 1943, were disappointing when they were tried, generally losing in range and sensitivity due to high humidity.[4] There was no Gee system, but an East India Loran chain was in operation just before the end of hostilities, and further cover for the whole command was in the planning stage. Aircraft crews were not encouraged to use W/T D/F on operational sorties, emphasis being laid on the fact that use of H.F. or M.F. D/F revealed to the enemy the airfield to which aircraft were returning and the number of aircraft operating; the use of M.F. beacons was encouraged as it revealed neither. An energetic navigator could maintain a fair idea of his position by the use of astro-navigation and loop bearings, although generally speaking more use could have been made of loops.[5] In many instances the value of loops was limited owing to the distance from M.F. beacons at which operations were carried out, but navigators praised the assistance they got from beacons when flying over the Bay of Bengal, an error of not more than 18 miles being general at 250 miles range. Even these results might have been improved if regular checks of the loops for quadrantal error had been carried out. Some U.S.A.A.F. radio ranges were conveniently situated and gave useful service, and aircraft radio compasses were useful for homing.

Atlantic Ferry Routes

A decision to open air reinforcement routes across the North and South Atlantic was taken in October 1940, and Ferry Command was formed at Montreal on 20 July 1941 to organise and control the delivery of aircraft across the

[1] No. 224 Group O.R.B. Appendices, October 1942.
[2] A.C.S.E.A. O.R.B. Navigation Appendices, February 1945.
[3] A.C.S.E.A. O.R.B. Navigation Appendices, April 1945.
[4] A.C.S.E.A. O.R.B. Navigation Appendices, February 1945.
[5] A.C.S.E.A. O.R.B. Navigation Appendices, April 1945.

Atlantic.[1] The route followed was Montreal, Presque Isle, Goose or Gander, Nutts Corner, Prestwick; flying boats were routed through Boucherville, Botwood (Gander), to Largs, and through Bermuda and Botwood to Largs. Many aircraft using the North Atlantic ferry route refuelled in Iceland, and there was also a north-east staging route through airfields on islands on the west coast of Greenland and thence to Iceland and U.K.[2] Some flying boats flew from Bermuda to the United Kingdom via Gibraltar.

At first the most important radio aid on this route was long-range cathode-ray D/F, no other D/F system being capable of operating a fixing service at the distances involved. Radio ranges later came into general use, and M.F. D/F stations situated in western England and Scotland were also utilised, but the main aids, other than cathode-ray D/F, were Loran and Consol, which were not ideally situated to provide cover on the Atlantic routes. In September 1944, a flight was carried out by a Transport Command aircraft to compare, in operational conditions, the existing systems of radio aid to navigation as applied to trans-oceanic navigation.[3] The route followed was Prestwick, Iceland, Greenland, Newfoundland, Montreal, Toronto, Montreal, Newfoundland, Azores, United Kingdom. The report on the flight showed conclusively that Consol was superior to Loran and cathode-ray D/F in almost every way. It was at least as accurate, its reception was the most reliable, and its range was much the greatest. Where the cathode-ray system had a day range of 300 to 600 miles and Loran a day range of 700 miles, Consol had a reliable day range of 900 to 1,200 miles. The cathode-ray D/F organisation, however, retained its value for control purposes and as an aircraft safety organisation.

The South Atlantic route began at Miami and continued through Porto Rico, Trinidad, British Guiana, Belem (Brazil), Natal (Brazil), and thence across the South Atlantic to either Accra or Robertsfield (Liberia), medium-range aircraft staging at Ascension Island.[4] Having reached West Africa, aircraft then flew northwards to the United Kingdom or eastwards on the trans-African routes to the Middle East and beyond. H.F. D/F was available at coastal airfields from the Gold Coast to Gambia, and these stations also operated M.F. beacons.[5] American radio ranges were much used on this route, but the basic radio aid continued to be H.F. D/F. At times there were reports of inaccurate bearings, but such reports were seldom accompanied by documentary evidence, and H.F. D/F stations in West Africa gave a sound service to those operators who appreciated the limitations of this form of direction-finding.

Mediterranean Reinforcement Routes

By 1940, aircraft were already flying to Egypt via Gibraltar and Malta, and many other possible routes were open to development so long as France and her North African colonies held out against Germany. But with the collapse of France in June 1940, the only feasible air route for medium-range aircraft was United Kingdom–Gibraltar, Gibraltar–Malta, Malta–Egypt. The first two legs were too long for most fighter aircraft, and enemy air activity was liable to be encountered over parts of all three. Space at Gibraltar was extremely limited, so that its handling capacity restricted the potential flow of

[1] A.H.B./IIJ/15/5. Aircraft general arrangements including briefing and training of crews.

[2] A.H.B./IIJ/4/1. Reinforcement Routes.

[3] Transport Command O.R.B. Signals Appendices, September 1944.

[4] A.H.B./IIJ/4/1.

[5] A.M. File S.13293.

aircraft; in addition an attempt by enemy forces to capture Gibraltar was a possibility, the outcome of such an attempt being uncertain. Malta, too, was extremely vulnerable to air attack from the moment Italy entered the war. Already, before the German *blitzkrieg* of 1940, a possible reinforcing route involving the movement of aircraft to Lagos by sea and thence, following assembly, by air through northern Nigeria, French Equatorial Africa and the Sudan, to Egypt, had been planned. A decision to open this route was taken in October 1940.[1] So by late 1940 the Middle East had two channels of reinforcement, one for twin-engined medium and long-range aircraft by air through the Mediterranean, flown by crews who would normally go with the aircraft to squadrons, and one for short, medium and long-range aircraft by sea to West Africa and thence by air, flown by crews specially chosen for a tour of ferry work.

The presence of the threat of enemy air activity over long stretches of the route from the United Kingdom to Egypt via the Mediterranean meant that W/T was used as little as possible. In any event, there were no intermediate stations for an aircraft to work with, although there were useful enemy and neutral beacons and broadcasting stations on the first two legs.[2] Navigational aids on this route were so few that the fullest advantage had to be taken of those that existed; yet in April 1941, Air Headquarters Malta reported that a number of aircraft losses and many narrow escapes had been caused by lack of W/T communication, usually attributable not to technical failure but to inefficient operating, the inefficiency being due to either inexperience or incompetence. This report disclosed that even the most rudimentary aspects of an operator's task, log-keeping, ability to tune correctly, to change frequency, to interpret operating signals, and elementary fault-finding, were being done badly.[3] Signals briefing, too, was considered to be inadequate. Another important point was that many of the crews flying on this route had just completed O.T.U. training, and many navigational errors were due to the inexperience of pilots and navigators. Very few astro-navigation fixes were taken, and many navigators were unable to take drifts over water. Reliance on meteorological forecast information, encouraged by the accuracy of internal forecasts in the United Kingdom, was quite unwarranted in the Mediterranean area, where forecasting was extremely difficult due to lack of information.[4] These factors made competent operating of increased value, but, unhappily, operators suffered from the same defects of inexperience as other crew members. In addition, hampered by the reluctance of captains to sanction the breaking of W/T silence, and by the fact that their aircraft often flew at very little above sea level, and experiencing the same equipment difficulties as were general at that time, they were not always able to obtain navigational aid when the need arose.

The first major air activity at Gibraltar began early in 1940, when aircraft of Coastal Command began operating from there. From 1941 onwards, however, although Coastal Command continued to operate, the number of reinforcement aircraft passing through Gibraltar *en route* to Malta and the Middle East increased rapidly and constituted by far the greater part of all aircraft movements. At that time, radio aids to navigation were almost non-existent at Gibraltar. There was a Royal Navy H.F. D/F station, which had been installed in 1937, and R.A.F. aircraft used it for homing, but bearings were not accurate

[1] A.H.B./IIJ/15/5.
[2] A.H.B./IIJ/4/23. Air Routes General Signals Instructions.
[3] A.H.B./IIJ/15/5.
[4] A.H.B./IIJ/15/5.

enough to be wholly acceptable. There was also a ship's loop which had been installed by the Royal Navy before the war, and this was taken over by the R.A.F., who maintained a watch on 340 kilocycles per second. Bearings were greatly affected by coastal refraction and diurnal effects, and sense was unreliable, but nevertheless the loop gave useful service. However, it was obvious that a good H.F. D/F station was badly needed, although the topography of Gibraltar made the siting of a station on land impracticable; the only feasible location was in the bay itself.[1]

The bay to the west of the airfield was two to three fathoms deep and had a tidal rise of only six feet. It was protected in part by the North Mole and was subject to heavy swells only on occasion. It was at first proposed to build an island of wooden piles on which to erect the H.F. D/F station, but such a course was found to be impracticable owing to the heavy cost. When, therefore, in March 1942, rapid development of an extension of the runway into the west bay was begun, application was made for a small spit to be built on the north side of the runway in order that site possibilities might be tested. Permission was given and the tests were favourable, so a mole was subsequently built on the end of the completed runway, extending north of it for a distance of 250 feet. Late in April 1943 work on the D/F site itself began, and the station was completed and tested in June and July 1943. Good results were obtained up to a distance of 450 miles. Additional aids to navigation available at Gibraltar were an M.F. beacon, a Naval Broadcast M.F. beacon, and a responder beacon, and later a V.H.F. R/T ground station.

The first D/F station to be operated by the R.A.F. had been erected at Ta Silch, Malta, where the R.N.A.S. had sited D/F equipment in the First World War, in 1924, and it had provided a good service over the years. The provision of new equipment became essential and in 1938 the installation of twin M.F. channels, one Service and one civil, was planned. The new station began operating shortly after the outbreak of war.[2] Installation of the first H.F. D/F station in Malta was completed in May 1940, and subsequently three additional stations were erected; they were, of course, used as much by operational as by reinforcement aircraft. An M.F. beacon was also established, and V.H.F. D/F was introduced in 1942. The beacon was generally switched on two hours before the estimated time of arrival of aircraft, and it is notable that there is no evidence of enemy attempts to meacon its transmissions, although such a radio countermeasure presented no difficulties. In spite of the number of aids available, many aircraft failed to survive the Gibraltar–Malta leg of the route.

The fluid situation obtaining in the Western Desert for long periods made accurate navigation from Malta to Egypt essential. An H.F. D/F station located at Mersa Matruh provided an excellent service, and valuable assistance was provided by D/F stations sited in the Delta area. However, as late as May 1942 Headquarters R.A.F. Middle East was reporting that a considerable proportion of reinforcement aircraft were making no use of the D/F service, were failing to maintain a proper listening watch, and were not answering control signals.[3]

One of the advantages gained from the success of Operation Torch and the advance from El Alamein was that all types of aircraft could be ferried to the

[1] Coastal Command Signals Review, Volume I, No. 2, February 1944.
[2] A.H.B./IIJ/15/5.
[3] A.M. File S.45161.

Middle East and India along the North African coast, as soon as staging post facilities were ready. This relieved the pressure on Malta, where shortage of petrol for refuelling had restricted the flow of reinforcement aircraft, and also released shipping which had previously been used to carry aircraft to West Africa; lack of suitable ships had made the shipping of twin-engined aircraft a most difficult problem. From December 1942, all aircraft, except Bisleys, Beaufighters, and Beauforts, were routed from Gibraltar direct to El Adem, landing at Malta in emergency only. A small number of Wellingtons flew direct from Gibraltar to Benina.[1]

West and North Africa Reinforcement Routes

It was decided to inaugurate a West African reinforcement route on 20 June 1940, to provide a means of supplying aircraft to the Middle East at a rate comparable with the accelerated wastage expected consequent upon Italy's entry into the war. The decision was also influenced by the knowledge that the Mediterranean route to the Middle East would be jeopardised by the collapse of France.[2] The first survey flight over most of the proposed route had been made in 1925, and further flights culminated in the inauguration of a weekly Imperial Airways service from Khartoum to Kano in 1936, which was later extended to Lagos and then Accra and Takoradi. By July 1940, when the advance party of the R.A.F. arrived at Takoradi, a primitive communications network connected Takoradi to Khartoum through Accra, Lagos, Oshogbo, Kano, Maiduguri, Geneina, El Fasher and El Obeid. An M.F. D/F service was available at only four stations throughout the route, at Accra, Lagos, Kano and Khartoum, consisting of Marconi-Adcock stations with DFG. 10 receivers and an assortment of transmitters. It was, of course, possible for W/T stations not provided with D/F equipment to transmit so that aircraft could obtain loop bearings. Such an organisation might have been adequate for the volume of pre-war air traffic, but considerable expansion was obviously necessary to maintain the flow of aircraft envisaged in the reinforcement scheme. The most pressing need was for increased D/F facilities between Kano and Khartoum, a distance of over 1,700 miles, then covered by a D/F station at each end only. A new signals organisation brought into force for the start of ferrying added M.F. D/F at El Geneina and Kosti, with aircraft installations to work on the ground as beacons at Maiduguri, El Geneina, and El Fasher.

The first despatch flight began on 19 September 1940, but for security reasons aircraft were instructed to maintain wireless silence throughout the flight, except in emergency, and the efficiency of wireless navigational aids along the route was not fully tested. However, in the meantime a request was made for H.F. D/F facilities at Kano and Geneina, and for a beacon at Lagos. The Air Ministry agreed to the provision of a beacon at Lagos but stressed that it was to be used sparingly, and H.F. D/F equipment was despatched for installation at Kano, Maiduguri and El Geneina. On 20 December 1940 this equipment was at Takoradi awaiting transport.

Meanwhile, one of the early convoys made a forced landing south of El Geneina following wireless failure. Of the seven aircraft in the convoy, four were completely destroyed; one pilot was killed. It was later established that the wireless failure, which had been directly responsible for the forced

[1] A.H.B./III/16/5.

[2] A.H.B. Narrative, 'The Middle East Campaigns', Volume X—'The West African Air Reinforcement Route'.

landing, was due to inexperience on the part of the operator, and after this accident the importance of using only highly-experienced operators on the route was recognised. Great care had been taken in the selection and training of pilots and navigators, but the same care had not been taken up to that point in the choice of wireless operators.[1] In December 1940 Air Marshal Tedder, on his way to take up the appointment of Deputy A.O.C.-in-C., R.A.F. Middle East, surveyed the route. The key to the whole route, he thought, was efficient W/T and D/F; maps over long stretches of the route were almost useless, and for some stretches, and particularly between Fort Lamy and El Geneina, there were practically no landmarks. The pilot of the aircraft in which Air Marshal Tedder travelled, who had been over the route a number of times, considered that without D/F the Fort Lamy–El Geneina leg was a gamble, and the Air Marshal endorsed this view. '. . . Further steps will have to be taken . . .' he said, '. . . to ensure that the wireless personnel in the aircraft are really experienced men . . .'[2]

A modified signals plan for the route was drawn up in April 1941, approved by the Air Ministry in May, and fully implemented by August. Main staging posts, at which H.F. D/F stations and M.F. beacons were installed, were established at Accra, Lagos, Oshogho, Kano, Maiduguri, El Geneina, El Fasher, Khartoum, and Wadi Halfa. Subsidiary staging posts, which were provided with H.F. D/F equipment with low-power transmitters Type F.3, were established at Ati, El Obeid, and Luxor. Civil M.F. D/F stations already existed at Accra, Lagos, Kano, El Geneina, Khartoum and Wadi Halfa, and a station was planned at Maiduguri. From then onwards D/F facilities on the route proved to be adequate, and with the establishment of a parallel route for aircraft operated by the U.S.A., installation of suitable radio facilities continued to increase.[3]

In view of the success of the Allied forces in North Africa, the Air Ministry decided in January 1943 that all twin-engined aircraft were to fly to the Middle East and beyond via the Mediterranean, and this meant a considerable reduction in assembly at Takoradi.[4] Later, in August 1943, it was also decided to route Hurricanes via the Mediterranean, and in consequence the number of aircraft handled at Takoradi decreased steadily and ceased altogether in October. However, American aircraft were still arriving at Accra, which became the major terminal in West Africa, and R.A.F. crews continued to ferry American aircraft to the Middle East and India. The organisation of staging posts remained in being, although there was some retrenchment since convoys of twin-engined aircraft were able to over-fly minor staging posts and even some of the major ones. A route of three legs, Accra–Maiduguri, Maiduguri–Khartoum, Khartoum–Cairo became commonplace; but the importance of D/F facilities on this route was undiminished.

The North Africa route began in French Morocco at Rabat Sale, and continued through Ras el Ma (near Fez), Oujda, Biskra, Castel Benito, Marble Arch, El Adam, Mersa Matruh, to Cairo West. H.F. D/F, V.H.F. D/F, and M.F.

[1] A.H.B. Narrative, 'The Middle East Campaigns', Volume X—' The West African Air Reinforcement Route'.

[2] A.M. File S.7580.

[3] By September 1941, British and American aircraft were being off-shipped and assembled at Port Sudan on the Red Sea, and a reinforcement route was opened to Egypt via Summit and Hurghada, and also through Atbara and Wadi Halfa. H.F. D/F and M.F. beacons were installed.

[4] A.H.B. Narrative, 'The Middle East Campaigns', Volume X—' The West African Air Reinforcement Route'.

beacons were installed at each staging post.[1] Some of the larger aircraft overflew one or more posts. There was a subsidiary route from Gibraltar via Cape Tenes, Maison Blanche, Biskra to Castel Benito and onwards with similar facilities. Later, a reinforcement route to Italy from North Africa was provided with major staging posts at Malta, Catania, Naples and Rome, and the navigational aids made available included H.F. D/F, V.H.F. D/F and M.F. beacons.[2]

India and Far East Reinforcement Routes

Aircraft destined for India were first ferried either by the West Africa route or the North Africa route to Khartoum or Cairo. From the Middle East there were two possible routes, both of which were used regularly; a northern route through Lydda (Palestine), L.G.H. 3, Habbaniya, Shaibah (Basra), Bahrein, Sharjah, Jiwani, Karachi, and a southern route through Khartoum, Asmara, Aden, Salalah, Masirah, Jiwani, Karachi.[3] Short-range aircraft on the southern route followed the route Atbara, Summit, Bahdar, Massawa, Assan, Perim Island on the long leg between Khartoum and Aden. At first only a civil M.F. D/F service was available, but the installation of H.F. D/F had been completed by August 1943.[4] Major staging posts on both northern and southern routes were also provided with V.H.F. D/F and M.F. beacons.

The civil M.F. D/F service in India was used to form a reinforcement route in December 1941, when a number of Hudsons were ferried from the United Kingdom via the Mediterranean, Suez, Persia, across India, and then south-east through Rangoon to Singapore. Subsequently, poor lines of communication and the vast distances involved led the air forces to develop the potentialities of air transport vigorously, and eventually H.F. D/F and V.H.F. D/F equipment was installed at 18 staging posts. The new D/F organisation extended the number of stations operating on M.F., and provided an H.F. D/F service on the transit frequency on the trans-India and other internal routes, but development of V.H.F. D/F facilities was slow due to lack of equipment, and by the end of 1943 V.H.F. D/F was available, outside the operational areas, only at Jodhpur, Delhi and Allahabad.[5] Low-power M.F. beacons, and some U.S.A.A.F. radio ranges, were also available. This route, together with other internal Indian routes, was taken over by the newly formed Transport Command in 1943.[6]

The air route from Karachi over the Himalayas to China, the only practicable supply line to the Chinese Army following the loss of Burma, was known as 'The Hump'. It was operated by the U.S.A.T.C., and wireless aids were practically non-existent at first, later consisting almost entirely of radio ranges. The route traversed the most difficult terrain, crossed enemy-held territory, was liable to fighter interception, and yet approximated to an internal U.S.A. airline, aircraft flying down the radio range and being in continual R/T contact with the ground. R.A.F. flights over 'The Hump' conformed to the American organisation.[7]

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[1] A.H.B./IIJ/4/1. [2] A.H.B./IIJ/4/1. [3] A.H.B./IIJ/4/1.

[4] R.A.F. Middle East O.R.B. Signals Appendices, August 1943.

[5] Transport Command O.R.B. Signals Appendices, January 1944.

[6] Transport Command was formed on 25 March 1943.

[7] Transport Command O.R.B. Signals Appendices, March 1944.

CHAPTER 23

AIRCRAFT COMMUNICATIONS

All experience gained with aircraft up to the end of the First World War, in the R.N.A.S., the R.F.C., and later the newly formed Royal Air Force, combined to illustrate the enormous increase in operational scope and value of aircraft when they were equipped with efficient wireless communication equipment; in fact, the majority of aircraft were unable to fulfil adequately the role allotted to them without it. Wireless equipment was first used in Service aircraft in 1912, and the first battle in which aircraft radio became a major factor was that of Festubert in May 1915. Preparations for the engagement consisted of observation by aircraft for artillery whilst guns were registered against trenches and strong-points within the enemy lines, and for the first time aircraft were specially detailed to report progress of the land battle by wireless, four aircraft of No. 16 Squadron being used for this purpose. From those beginnings a system of close-contact patrols for reporting infantry movements was developed. By the end of 1916 the strength of wireless personnel in the R.F.C., 200 officers and 2,000 operators and mechanics, was greater than the total 1914 strength of the R.F.C., and it had been decided to erect permanent W/T ground stations at all important aircraft bases in the United Kingdom. In 1918 the W/T research establishments of the R.N.A.S. and R.F.C. were amalgamated to form the R.A.F. W/T Establishment at Biggin Hill.

Design of Aircraft Radio Equipment 1919–1923

At the conclusion of the First World War it was evident that, owing to the great increase in use of wireless by aircraft, employment of the spark system of transmission in congested areas would have to be abandoned, because of the wide band of interference it caused and its flatness of tuning, in order to allow the requirements of all three Services to be met. In 1919, therefore, a series of inter-Service conferences was held, at which it was decided that all future equipment used by the R.A.F. and the Army in the field should be designed on a system calculated to reduce considerably interference caused by the spark system and so enable more individual communication to be carried on in a given area. As the decisions involved complete re-design of nearly all Army and R.A.F. apparatus, a scheme of apportioning wavelengths to the various Services was adopted, allowing for an overlap to cater for inter-Service co-operation.

T.25 and R.31 equipment was designed for the transmission and reception of R/T messages between close reconnaissance aircraft and Army units, and for R/T communication in the air between aircraft.[1] Unlike its wartime equivalent, the Telephone Wireless Aircraft Marks II and III, the installation worked on fixed aerials, thus doing away with the trailing aerial, which had been one of the greatest disadvantages in the use of R/T in operational aircraft. The apparatus

[1] A.H.B./IIA/1/53.

was operated by the pilot by means of a mechanical remote control system. The ranges obtained varied, but in the Bristol Fighter the average ranges were 25 miles air-to-ground, 5 miles air-to-air, and 8 miles ground-to-air. The first production models, 80 in number, were delivered by the contractors in 1924. The weight of the total installation was approximately 83 pounds.

The T.23 transmitter was designed to meet the needs of artillery co-operation, for the transmission of gunfire corrections to battery receiving stations. It radiated I.C.W. (interrupted continuous waves), which caused far less interference than the spark type, and the installation weighed 65 pounds. The pilot was provided with remote control located on his instrument dashboard and a morse key. The transmitter operated with a 200-foot trailing aerial. The wartime equivalent of this transmitter was the spark transmitter (Nos. 1 and 2). The T.23 was tested at Aldershot in 1921 and later introduced in all army co-operation squadrons.

The T.21A and Tf installation, designed during the war for continuous-wave transmission and reception, primarily for naval co-operation purposes, proved so efficient that it was quickly adopted for long-distance reconnaissance purposes. There was originally an attachment for radio telephony but this fell into disuse. The installation was subsequently introduced into all bombing and army co-operation squadrons, at home and overseas, and had become standard equipment in them by 1928. The total weight of the installation was 75 pounds. Range varied in different types of aircraft, but averaged 300 miles air-to-ground, 40 miles air-to-air, and 200 miles ground-to-air. The transmitter T.21A was one of the most efficient wireless sets of similar power and size in existence at the time, and although considerable skill was needed on the part of the operator to obtain good reception with the Tf in the air, remarkable results were achieved with the installation, which was still in use in the Service until a few years before the Second World War.

At the end of 1923 trials of the T.22 transmitter were about to commence. It was intended as a replacement for the T.21A, and it had been designed with the advantage of several years experience gained with this type. The waveband was extended, and the telephony attachment was expected to give better results than had been obtained with the T.21A. It was expected that future modifications would enable the apparatus to be used not only for air-to-ground W/T and R/T but also for short-distance air-to-air R/T on a fixed aerial.

Air Staff Policy 1924 and 1928

At the beginning of 1924, future policy with regard to the installation of W/T, R/T and D/F equipment was considered by the Air Staff, and although it was felt that a comprehensive statement of policy was premature in view of limited experience of the subject, it was decided to formulate a course of action with a view to finding out what results could be obtained with existing apparatus and what line future development should follow.[1]

As a result of Air Staff decisions, every aircraft of one squadron, No. 207 Squadron, was equipped with the necessary wiring and fittings to enable it to carry a W/T installation with trailing aerial, and an R/T installation with fixed aerial, but only sufficient equipment was provided to enable the leader and

[1] A.H.B./IIA/1/33. *See* Appendix No. 11.

deputy-leader to use two-way W/T and R/T, all other aircraft being provided with R/T reception only. This meant that, with D/F equipment, leader and deputy-leader aircraft carried wireless installations weighing 140 pounds and all other aircraft equipment weighing 40 pounds. Two W/T ground stations were erected to work with this squadron. Other Air Staff decisions made at this time were that the first new day-bombing squadron was to be equipped in the same way as No. 207 Squadron, except that all aircraft were to be equipped with two-way R/T to enable formation flying tactics and drill to be practised; other two-seater day-bombers were to be suitably modified to enable similar installations to be made. All aircraft of No. 7 Squadron were equipped with two-way W/T, and as each of the next three new night-bombing squadrons was formed it was equipped in the same way.[1] The Air Staff was particularly concerned with three problems of the future: the outmoding of the trailing aerial in all aircraft which might have to fly in formation, the extending of the receiving range of apparatus without any increase in weight, and the design of a set which would combine the functions of telegraphy and telephony.[2]

Progress in the next few years was disappointing, and there were many delays in the supply and fitting of equipment.[3] Most of the trials carried out during this period concerned D/F methods, some of which, such as wing coils and the rotating beacon, did not depend on two-way W/T communication, but all aircraft equipped with two-way W/T made use of the two ground stations at Eastchurch and Worthy Down, and W/T communication was good. However, an equipment policy which resulted in aircraft being liable to carry two transmitters (one for W/T, one for R/T) and three receivers (W/T, R/T and wing coil) could obviously be only temporary, and by 1927 the most urgent need was for the design of a general-purpose transmitter-receiver which would fulfil all necessary functions. In army co-operation squadrons, whose functions depended mainly on the effective employment of aircraft radio, a three-panel system of installation was used. Short-range reconnaissance involved the use of T.25 and R.31, long-range reconnaissance the use of T.21A and Tf, and artillery co-operation the use of T.32, a development of T.23. Although the removal and installation of each separate panel was comparatively simple and normally took only a few minutes, the functions of aircraft were restricted, and the loss of flexibility was uneconomic.

In February 1928 the Air Staff reviewed the experience of previous years, and found that installation of all the individual sets required at the time was so complicated and cumbersome as to interfere with other duties of the aircraft crew.[4] It was therefore decided to introduce a fresh interim policy, to be proceeded with until sufficient experience had been gained with improved apparatus to enable a final policy to be declared.[5] The main points of the interim policy were that a combined set for day bombers, capable of providing two-way W/T or two-way R/T, to operate on a fixed aerial, was to be produced for Service trials as soon as possible. Pending production and trials of this apparatus, no definite decision on the tactical use and employment of wireless in day bombers was made. All day-bomber aircraft were wired to take, and three aircraft per squadron were fitted with, two-way W/T, to enable squadrons to

[1] Provision was made for 100 per cent spares to be held in each instance.
[2] A.H.B./IIA/1/53. [3] A.M. File S.23185. [4] A.M. File S.23185.
[5] A.H.B./IIA/1/53. *See* Appendix No. 12.

practise D/F navigation by the Bellini-Tosi method and two-way W/T communication with ground stations and with other aircraft. One flight of No. 100 (Bombing) Squadron was equipped with two-way R/T of the same type as that already in use in fighter aircraft, to enable experience to be gained in the tactical handling of bomber formations using R/T. In specifications for future day-bomber aircraft, details of the wireless equipment to be carried were to be omitted, but a space of specified dimensions was to be reserved for wireless apparatus. The dimensions were to be arrived at by the R.A.E. and were to be of a size to ensure that new apparatus under development could be carried. A new W/T receiver for night bombers, capable of use for two-way W/T or wing coil reception, was to be completed at an early date and given Service trials in a night-bomber squadron with a view to its general introduction when proved satisfactory. All future night-bomber aircraft were to be fitted with wing coils. All night-bomber aircraft were to be fitted with two-way W/T to enable them to practise D/F navigation by the Bellini-Tosi method and two-way W/T communication with ground stations and other aircraft.

Development and Production 1928–1935

In the next few years research and development were continued, but operationally there were very few developments, policy being governed by the Air Staff statement that definite decisions on the tactical employment of wireless in aircraft could not be made on the basis of results with the existing obsolete equipment. The second experimental receiver for night-bomber aircraft, for long-wave reception and wing-coil D/F, was still undergoing modification in 1929, and delay in its production was made the subject of investigation and report.[1] Production of six Service trial models was given the highest priority, but still no delivery date could be given. Finally, one receiver was ready for installation in February 1929, and was subsequently styled the R.68. The requirement that W/T equipment was to be capable of use with both rotating beacons and D/F ground stations was confirmed in June 1930, but the new experimental transmitter-receiver, the TRX.3, which weighed 130 pounds, was adjudged to be too heavy for day bombers. Although only two aircraft in each formation were fitted with W/T in day-bomber squadrons, the speed of the whole formation was reduced, and the external wind-driven generator was another source of loss of airspeed. In addition, the bomb load was also unacceptably reduced. The TRX.3 was therefore rejected for use in day bombers, and a conference was called at the R.A.E. to discuss W/T and R/T requirements in those aircraft.

As a result of the conference, held on 22 December 1930, specifications were formulated, for development in 1931, of a day-bomber transmitter/receiver with a range of up to 300 miles, and of a battery-operated transmitter/receiver of lower power known as the TRX.9, which was the prototype of the TR.9 used by Fighter Command in the Battle of Britain. Service trials of the TR.9 began in 1932. At 5,000 feet R/T ranges were 30 to 40 miles air-to-ground and 10 to 12 miles air-to-air. In June 1931 a clear requirement for new W/T equipment for night bombers was stated, to include D/F by the Bellini-Tosi method and the rotating beacon up to the maximum range technically possible with existing ground equipment, estimated at 500 miles.[2] The weight of the equipment was to be restricted to 120 pounds, but it was found that this requirement was not compatible with a range of 500 miles, and in order to keep the weight down

[1] A.M. File S.26997.

[2] A.M. File S.29124.

range was sacrificed and was finally agreed at 300 miles. This equipment was given its first trials at Worthy Down and Boscombe Down in March 1935, and as a result there emerged a new general purpose W/T installation, the R.1082/T.1083. The R.1082/T.1083 and TR.9 installations contained many faults and limitations, and, as might be expected, were obsolescent by September 1939, but they represented the results of a long struggle for improved wireless equipment at a time when the importance of aircraft radio was not universally accepted or understood.

The years 1919–1935 were difficult years in the Service for the development of wireless equipment, as may be gauged from the fact that the Tf receiver and the T21.C transmitter, a modified version of the T21.A, used in the later stages of the First World War, were still in general use at the end of the period. Three main considerations had determined the policy of provision of aircraft radio; the number and variety of operational requirements, the necessity of financial economy, and the swiftly-changing process of technical development. They made any long term production programme impracticable; the requirement for each different function was therefore reviewed at fairly short intervals of time, and provision was made on the smallest possible scale on each occasion. As a result of the necessity for a short-term policy, forced upon the Air Staff by the three main factors, the requirements of bomber, fighter, army co-operation squadrons, of general purpose squadrons overseas, of reconnaissance squadrons, flying-boats, and Fleet Air Arm units, had to be considered separately and no form of standardisation was possible. Interference caused by the spark method of transmission had resulted in the development and introduction of continuous-wave transmission. Congestion on medium frequencies was followed by the exploration and use of higher frequencies. The ever-increasing use of H.F. telegraphy and telephony by all nations necessitated close adherence to allotted frequencies and the development of transmitters of sufficient power and stability to overcome increasing interference. This increasing interference was a great stimulus to the development of equipment designed to operate in the very high frequency, or V.H.F., bands.

In 1928 research into the general properties of V.H.F. for wireless communications was provisionally recommended for inclusion in the R.A.E. research programme, but before this the Air Ministry had become interested in a scheme proposed by Mr. R. C. Galletti for generating a parallel beam of short wireless waves.[1] After a preliminary demonstration in March 1927 it had been suggested that the R.A.E. should make a thorough investigation of the proposed system but no suitable personnel could be made available for the project. The Signal School of the Royal Navy conducted an investigation and reported adversely on the proposed scheme. The matter was therefore dropped but in 1929 interest was revived, and flight trials carried out in May 1930 produced such encouraging results that further investigation was included in the research programme of the R.A.E., where a super-regenerative receiver and mobile transmitter were designed and made for experimental use.[2] In May 1931 it was decided that the method was not sound fundamentally and development of the project was abandoned. During the course of the investigations progress was made with the design of a complete low-power transmitter and a receiver for use on the 150 to 100 megacycles per second frequency band, and in March 1931 the first

[1] A.H.B./IIE/249. 'The V.H.F. R/T System' by Jay.

[2] The highest frequency used in the experiments appears to have been 100 megacycles per second.

of a long series of experiments was begun with the aim of gaining more knowledge of the properties and characteristics of such frequencies. The experiments formed the basis for development of V.H.F. wireless equipment.

By the end of 1932 flight tests of improved equipment enabled the R.A.E. to arrive at certain broad conclusions. Frequencies between 109 and 120 megacycles per second were suitable for many ground-to-air, air-to-ground and air-to-air communication purposes. Range was about equal to the optical path between transmitter and receiver: it was considered that this effective limitation of range would be valuable in certain circumstances. Vertical polarisation was preferable and super-regenerative receivers were unlikely to be suitable for Service use because they were not sufficiently selective and were not easy to tune.[1] Until 1935 research and development were devoted mainly to improving the design of transmitters and receivers, and no fundamental circuit modifications were included. Some improvement in transmitters was made possible by the introduction of special V.H.F. transmitting valves, but development of receivers was very much hampered by the lack of really suitable valves; the first samples of 'acorn' valves, for example, were not received at the R.A.E. until the end of 1934. Consequently only super-regenerative receivers were available for experimental use; such a receiver, the R.1110, was developed for aircraft of the Fleet Air Arm to enable them to home to beacons on a frequency of 210 megacycles per second.

During 1933 it had become apparent that Service requirements and technical development had at last reached a stage which made it possible to visualise some degree of standardisation in the immediate future, and in 1934 a line of policy was decided which marked a big advance in this direction.[2] Discussions centred around the possibility of reducing the aircraft sets in use to two only, an R/T set for fighters, day bombers and trainers, and a general-purpose set for all other types of aircraft. However, owing to the fact that the Hart type of aircraft then in use for army co-operation (Hart, Audax, Osprey, Hardy) would not accommodate a general-purpose set of the type visualised, it was realised that the standardisation aimed at must be attained in at least two steps, and it was therefore decided to reduce the number of sets under development to three, an R/T set for fighters and light bombers, an interim general-purpose set for all squadrons other than army co-operation, and an army co-operation installation. Later, upon the replacement of the Hart type of aircraft for army co-operation, the requirement would be reduced to two main installations. There was, however, one qualification; the replacement for TR.9 would include facilities for modulated C.W., listening through, and coil D/F in the receiver, to make it meet the requirement in light bombers for a 'pocket' general-purpose set.

Improvement of Equipment 1935 to 1939

The operational requirement for radio in fighter and bomber aircraft was consequently defined as:—[3]

Fighters. Two-way H.F. R/T for tactical control of fighter formations, at ranges up to 50 miles, with frequency-changing in the air and an increase in range to 80 miles to be aimed for ultimately. The necessity for the transmission of wireless signals by the aircraft for D/F was accepted. Intercommunication was necessary between pilot and air gunner in two-seater fighter aircraft.

[1] A.H.B./IIE/249. [2] A.H.B./IIA/1/53. [3] A.H.B./IIA/1/53.

Light Bombers. Three aircraft in each squadron were to be equipped for W/T and normally in a squadron formation two aircraft were to carry W/T, capable of a range of up to 300 miles on M.F. and greater ranges on H.F. H.F. R/T with an air-to-air range of 5 miles was also needed for fire control, co-ordination in wing formation, and pattern bombing. Intercommunication between pilot and air gunner was required.

Medium and Heavy Bombers. All aircraft were to carry W/T, capable of ranges of up to 300 miles on M.F. and up to 500 miles at 5,000 feet on H.F., and intercommunication between pilot and crew was required.

The situation in 1935, therefore, was that day and night fighters, which were both allocated the 4,286 to 6,667 kilocycles per second frequency band, were being fitted with the TR.9, whilst a replacement set of similar design but improved performance was planned for introduction in about 1938/39. Light bombers, which were allocated the 3,000 to 4,620 kilocycles per second frequency band, were being fitted with the TR.11, an R/T set of similar design and performance to the TR.9 but operating on a lower frequency range, the replacement set being the same as that being developed for fighter aircraft. Light bombers also carried W/T, operated on the same H.F. range as their R/T, and on the M.F. band of 143 to 400 kilocycles per second, and were using the T.21C and Tf, which was to be replaced by the interim G.P. set in 1936. Eventually this interim set would be replaced either by a more up-to-date G.P. set, developed to specifications drawn up by the Directorate of Signals, which was expected to be ready by 1939/40, or by the 'pocket' G.P. set produced from the new R/T replacement set. Medium and heavy-bombers, which were allocated the 3,000 to 4,300 kilocycles per second H.F. band and the 143 to 400 kilocycles per second M.F. band, were using the T.21C and R.68, which was to be replaced by the interim G.P. set in 1936. This in its turn was to be replaced by the new G.P. set in 1939/40. The installation in bomber aircraft of separate R/T equipment, the TR.11B, was begun in 1939, for inter-aircraft communication and local control. However, the rapid expansion of Fighter Command made it impossible to provide sufficient TR.11 equipment for Bomber Command without adversely affecting production of other equipment, and it was decided in March 1939 to equip all bomber aircraft with the TR.9D.[1]

There were two other operational requirements for aircraft radio communication; army co-operation and coastal defence. The equipment in use in army co-operation squadrons hitherto had been complicated by two factors: first three types of air reconnaissance had been required, close, medium, and artillery, and considerations of suitable frequencies for the distances involved necessitated the provision of three types of apparatus; and secondly, the necessity for carrying an air gunner who could devote all his attention to defence made it desirable for the W/T and R/T in close reconnaissance and artillery spotting to be suitable for operation by the pilot. A three-panel system had been evolved to cover the three different reconnaissance requirements, in which three interchangeable sets were fitted according to the requirements of the individual flight, but by 1932 this system had been superseded by a combination of the three transmitters and two receivers of the old system into one transmitter receiver, the TR.2. This apparatus marked a big advance in ease of maintenance and handling on the old three-panel system, but there were still several shortcomings, and replacement apparatus was therefore designed. Servic

[1] A.M. File S.4669.

trials were carried out and contract action taken in 1935. One of the most striking lessons of Army exercises of the early thirties was the gradually increasing difficulty of differentiating between close and medium reconnaissance areas, the development of mobility as a result of the mechanisation of ground forces causing the close reconnaissance area to be extended. A new transmitter, the T.1090, was produced to meet the Army requirement of R/T communication from ground to air, and four of these transmitters, mounted in Morris six-wheelers with improved layout and accommodation, completed Service trials in 1935. In addition, a general-purpose wireless tender, using the standard Albion two-ton chassis, was under construction, and the first of these vehicles was ready in 1937. It was thought that the interim G.P. set would meet all the coast defence requirements for multi-seater aircraft, with the TR.9 or TR.11 for all R/T requirements. Flying boats were operating with the TR.4, and coastal reconnaissance aircraft taking the place of flying boats were to use the TR.4 initially followed by the interim G.P. set when available. Spotter aircraft were operating with the T.21C and Tf, which was to be replaced by the interim G.P. set. Torpedo-bombers were to use the interim G.P. set and TR.9.

The performance of aircraft radio was improved by the introduction of engine-driven generators and more effective ground equipment. Engine-driven generators had been made necessary by the increasing drag effects on high-speed aircraft of air-driven generators, and with the general introduction of the interim G.P. installation the latter were withdrawn from service. The provision of receiving and transmitting apparatus installed at ground stations was governed by a replacement programme laid down in 1933/1934. The replacement transmitters were the T.70 and the T.77, which were due for introduction in 1936, and the T.1087, which was due for introduction in 1937. The T.70 was an interim set for R/T communication with aircraft pending the introduction of the T.1087. The T.77 was a low-power transmitter for M.F. and H.F. W/T communication with aircraft and for point-to-point working. R/T could be added where required. The T.1087 was a general purpose, low-power H.F. transmitter for W/T and R/T working to aircraft, point-to-point and general standby. The replacement receiver was the R.1084, a general purpose W/T and R/T receiver covering all R.A.F. frequencies. Other transmitters, used particularly for working with aircraft at long distances overseas, were the Standard Telephones and Cables Type M.13 and the Marconi S.W.B.8.B. The importance of inter-communication between crew-members was recognised, and an amplifier Type A.1134 was developed for use in all multi-seater aircraft where the number of positions to be covered was greater than the capacity of the G.P. set.[1]

The comparatively large number of R/T and interim general-purpose sets required, especially under the expansion programmes of 1936, resulted in a departure from the previous practice of hand-production in the wireless industry. The TR.9 was made on quantity-production lines, and although delays in securing initial supplies resulted, valuable experience was gained, as a result of which the industry was soon in a position to produce large quantities of this particular set at short notice. The R.1082/T.1083, too, was made partly by quick-production methods, and it was decided that in future all sets would be designed for quantity production.[2] Production of wireless equipment was by then going

[1] A.H.B./IIA/1/53.

[2] A.H.B./IIH/241/10/16. Bomber Command File Signals Policy.

some way towards meeting the increased operational requirements caused by the greater speed and ranges of aircraft and their need to fly in unfavourable weather conditions. The Bellini-Tosi M.F. D/F system had been greatly improved by the substitution of new direction-finding equipment using Adcock-type aerials, and the whole service had been extended. H.F. D/F trials had been successful, and as a result the homing and fixing of fighters using the modified TR.9 had become a fundamental factor of fighter tactics. The installation of a network of H.F. D/F stations for fighter and bomber aircraft was in progress. W/T procedure for the identification of returning bombers, pending the design of equipment which would give automatic identification on ground radar screens, was under consideration. The installation of R/T equipment in all types of aircraft became approved Air Ministry policy in 1936. The limitations of the TR.9, coupled with growing interference on the H.F band in use, had stimulated the design and production of V.H.F. equipment.[1] The two basic wireless equipments with which R.A.F. aircraft began the war, the R.1082/T.1083 and the TR.9, were in quantity production. An inter-communication amplifier was being produced. Procedure for the use of W/T and R/T communication to assist landings in conditions of poor visibility and low cloud, and the testing and production of radio equipment specially designed for such landings, was in hand.

Inauguration of Regional Flying Control—1938

Progress in the design of aircraft since 1919, and recognition of their strategic and tactical potentialities, had indicated that air power would play an important and even a decisive part in any future conflict. The lessons of the early use of aircraft in the First World War, coupled with subsequent experience, suggested that for the proper conservation and efficient application of air power, radio communication with the ground for reporting, control, and navigational assistance was a fundamental need. That this aspect was recognised by the Air Staff in the inter-war years is evident from the decisions made to carry radio in all aircraft, in spite of the additional weight and space involved, and to rely on radio as the basic navigational aid. Yet, although the loss of payload involved was accepted, as well as the loss of security attendant upon the use of all forms of D/F, the value of W/T and R/T communication for general control purposes was not fully appreciated.

The use of aircraft radio for control purposes was far more advanced in civil aviation. The function of the civil aviation signals organisation was classified in two categories: provision of navigational assistance, inter-airport communication, and supply of meteorological information; and regulation of the movements of aircraft to minimise risk of collision.[2] A high proportion of communication between ground and air consisted of meteorological reports, and to avoid congestion a system of broadcast reports was instituted in 1936. But one of the two main functions of the organisation, assuming an importance equivalent to that of furnishing aircraft with navigational assistance, was the establishment of measures to prevent the possibility of collision as a result of the growing density of air lines. A standard organisation was devised to meet the need for a central control station regulating the movements of aircraft, and short-range stations whose function was to supervise and assist the approach and landing of aircraft were established. This organisation involved the creation

[1] A.H.B./IIE/249.

[2] A.H.B./IIH/241/10/16.

of main radio communication areas, normally about 150 to 200 miles square, arranged in an interlocking or honeycomb pattern to cover the entire country.[1] Each area was provided with a central station controlling radio traffic and regulating the movements of aircraft in its area. Within a main area were established, at the important airports, short-range stations on a different frequency from the main area station. The short-range stations were equipped with D/F equipment and low-power transmitters, and besides relieving the pressure on the main area D/F stations, they regulated the movements of aircraft in the controlled zone established round busy aerodromes, and were able to provide series of homing bearings to aircraft approaching to land.

The possibility of controlling aircraft tracks by some method of D/F first occurred to the Air Ministry in 1933, at a time when the risk of collision between aircraft flying on converging courses in cloud was causing much concern. Models of a visual azimuth indicator were produced for Service trials but the hope that the equipment would provide an efficient warning system was not fulfilled. An alternative suggestion for a W/T ground organisation to keep track of the position and height of aircraft formations and to control them so that collisions were avoided was put forward, but the idea was not followed up for some years.[2] It was not until 1937 that firm proposals were made for the incorporation of a new system of control for R.A.F. aircraft, and these proposals came from the Director of Training, following a visit to the U.S.A. in the summer of 1937 in which he was impressed by the methods of control of aircraft there, both on the ground and in the air. On his return the Director of Training recommended that the methods in use in the R.A.F. should be thoroughly overhauled. Up to 1937 the duties of control at airfields had been undertaken from a small watch hut by a duty pilot, usually a member of the squadron detailed for the day, with an airman of the watch, and sometimes a meteorological assistant.[3] The Director of Training recommended that the watch hut should be completely re-designed and enlarged into a control building, to be manned by an officer of at least flight lieutenant rank, who should be vested with authority to redirect aircraft in the air, to prevent the departure of aircraft if in his opinion weather conditions were unfavourable, to recall aircraft if the weather deteriorated after their departure, and to re-route aircraft if, through congestion or other causes, the route selected became dangerous.

The proposals of the Director of Training were given an added impetus in December 1937, when the A.O.C.-in-C., Bomber Command outlined measures he considered necessary for the organisation of regional airfields for the assistance of aircraft in emergency. The measures included :—

(a) A weather information service for conditions prevailing at airfields in different regions.

(b) A communications system whereby aircraft might contact control for general information and instructions.

(c) Homing devices.

(d) Aids to safe landings by night and in bad weather.

A Regional Control Committee was formed to consider the proposals, the first meeting being held on 12 January 1938, and as a result of a series of meetings, and reports from the commands, nine regional control stations were provided,

[1] A.H.B./IIH/241/10/16. [2] A.M. File 149335/31. [3] A.M. File 668431/37.

at Leuchars, Linton-on-Ouse, Waddington, Wyton, Abingdon, Boscombe Down, Mildenhall, Manston and St. Eval. They were selected primarily for their geographical locations so as to cover the greater part of England and southern Scotland. Each of the airfields was equipped with all available devices to enable an aircraft to land safely either in bad weather or when in difficulties, including H.F. D/F, *Lorenz* beam approach, night landing lights, and visual beacons. Control officers were specially trained and staffs were established to operate and maintain the various radio and electrical aids. Qualified meteorological staffs were also established to advise the control officers, and each station kept a record of the current weather conditions obtaining in its particular area, so that pilots could be kept informed in the air and either homed to one centre or diverted to another. Each centre was responsible for assisting any aircraft within its area by means of weather reports, information as to landing grounds, homings, controlled approaches, and diversions. Mildenhall, Abingdon, Boscombe Down, Linton-on-Ouse, and Wyton were completed by the end of 1938, and the remaining stations were completed shortly afterwards. In May 1939, agreement was given for the provision of a second H.F. D/F station at each regional control station.[1]

Before the outbreak of war, there was no continuous radio control of the actual landing of aircraft. The duty pilot was responsible for ensuring that the correct signals were displayed in the signal square on the airfield, including the wind direction and any special regulations in force, but A.P. 1460 ('Flying Regulations for the Royal Air Force') promulgated in March 1938 with the object of forming a collection of all current orders and instructions directly concerning pilots and crews of aircraft when engaged on flying duties, contained no mention of any kind of control of landings, the only regulation concerned with the actual process of landing being an instruction to pilots to see that the landing area was clear of obstruction. Pilots were responsible for complying with pyrotechnic and light signals at all airfields. This system was satisfactory only for individual aircraft in favourable weather under peacetime conditions; it was totally inadequate to meet wartime requirements. In war conditions whole squadrons might be expected to return to their bases within a short time, perhaps in bad weather, with most of the aircraft near the limit of their endurance and some damaged by enemy action. In such circumstances the individualism of pre-war days only added to the dangers, particularly when aircraft were jockeying for position on the approach. However, no control system to meet the problem had been developed up to the war.[2]

Operational Use of Aircraft M.F. and H.F. Communication Systems 1939 to 1942

Long-range communication with aircraft had been recognised as a requirement in Coastal Command as a result of experience gained during 1935, when the war between Italy and Abyssinia created international tension, and a high-power transmitter was installed at Mount Batten. It was used to work Bomber Command aircraft in the course of a series of training flights to France in July 1939, and the results encouraged Headquarters Bomber Command to urge the provision of a similar installation at High Wycombe. On the training flights the R.1082/T.1083 was used for maintaining two-way communication at distances of 400 to 500 miles.[3] However, a lack of discipline amongst operators

[1] A.M. File S.38120. [2] For full details see A.H.B. Monograph 'Flying Control'.
[3] A.H.B./IIH/241/10/24(A).

was revealed, messages being sent mostly in an insecure and uneconomical manner. The flights were the first occasion on which 'Syko' was used, and on some of the later flights a distinct improvement in its use was noted.[1] They brought a sharp reminder of the absence of security of wireless transmissions, the German news broadcast in English giving a concise review of the exercises by a high-ranking *Luftwaffe* officer.

Many of the early operations of Bomber Command were long-range reconnaissance in the Heligoland Bight and North Sea areas, at ranges up to 500 miles, and in those areas aircraft were required to send weather and reconnaissance reports the importance of which was sometimes so great that the success of operations depended upon them.[2] This circumstance gave added weight to the demands for long-distance communications, but there was some disagreement whether the need was as real as suggested. It was contended at Headquarters Bomber Command that the wireless operator was manning a gun throughout the period when long-distance communication was a possibility, and the likelihood of any appreciable volume of W/T traffic being passed to and from aircraft was thought to be remote. However, early in 1940 the Air Ministry authorised the provision of high-power transmitters at all bomber group headquarters locations, and by mid-1940 it had come to be appreciated that the ability to communicate with aircraft at long range was a necessity. At the same time the general opinion was that provision of the new Marconi W/T installation in aircraft would meet whatever operational requirement arose, but this set was still a long way from general introduction.

The expansion of the Royal Air Force which took place between 1939 and 1942 threatened, and in fact produced, a heavy overload on aircraft communications, which began to assume serious proportions in 1941. Several M.F. D/F sections were occupied in the identification of returning bombers, throwing an extra burden on the rest. H.F. D/F stations, although increased to a total of two at most operational bases, were liable to be overloaded on nights when Bomber Command operated in strength, especially if the weather deteriorated. The transmissions of routine messages on group operational frequencies soon built up to a considerable volume of traffic, and the landing of large numbers of aircraft in a short space of time presented exceptional problems of airfield control. Efforts to relieve congestion on D/F frequencies centred around the provision of an M.F. beacon system and the use of directional beams, and the problem resolved itself on the introduction of radar aids in 1942, but the danger of congestion on W/T and R/T communication channels remained. There was, in addition, a second ever-present danger in the use of W/T and R/T for whatever purpose; the danger that signals might be intercepted and the information extracted from them used by the enemy for operational purposes and to deduce the order of battle.

The main remedy for both dangers was the restriction of all aircraft communications to an absolute minimum. Indeed, prior to the outbreak of war it had been generally assumed that aircraft would maintain W/T silence until entering the identification zone on the return journey, except when requiring D/F for navigation purposes or in emergency, and it was not visualised that communications would be required on operational frequencies beyond the identification area. However, soon after the outbreak of war, operational groups felt the

[1] Syko was a cypher system for use in aircraft.   [2] A.H.B./IIH/241/10/24(A).

need for the control of individual aircraft at long range, and considerations such as the testing of equipment and the need for quick communication in emergency encouraged operators to make frequent use of their transmitters. Routine transmissions from aircraft such as requests for 'W/T Go', 'Operation completed' on leaving the target, or 'Operation abandoned' in some circumstances, and the transmission of operational messages by group headquarters for individual acknowledgment by aircraft, all contributed to overloading, besides providing a fruitful source of information to the enemy. And although at first all aircraft were not fitted with R/T, and the use of R/T for local control purposes was not general, this form of communication soon became popular for marshalling aircraft prior to night operations and for landing control. It was thought at first that the short range of the TR.9 would not render its use liable to general interception by the enemy.[1]

By mid-1941, it became apparent that control of individual aircraft on group operational frequencies, which was then customary, would soon become impracticable. Adequate communication became increasingly difficult, particularly on occasions when a high percentage of the bomber force was diverted on the return flight, and, from a security aspect, the growth of two-way communication between aircraft and ground stations for largely routine purposes had reached alarming proportions. The A.O.C. No. 5 Group informed Headquarters Bomber Command that, in the interests of security, aircraft in his group were maintaining virtually complete wireless silence until they returned to their bases, except in emergency.[2] 'Operation completed' and 'Operation abandoned' signals, for so long regarded by group operations rooms as essential to enable them to follow the course of operations, had been abolished, and with them had gone all frequency checks, W/T tests and W/T 'Go' signals. Q.D.Ms. were used only in emergency, and the use of the TR.9 for the marshalling and despatch of formations had been stopped, although No. 5 Group stations were still using R/T for bringing in aircraft returning from raids. It was decided in July 1941 that, for the time being at any rate, the value of R/T in the control of landings, especially in view of continued expansion, outweighed the disadvantage that the enemy might use the intelligence he gained from intercepting these signals to mount intruder operations.[3] The instances of interception and intrusion by German fighters in No. 5 Group were studied to see whether they showed any significant drop since the restriction of the use of W/T and R/T, and were found to be lower than those occurring in Nos. 1 and 3 Groups, but it was not thought that any safe conclusions could be drawn owing to various complementary factors.

It was assumed, and subsequent intelligence proved the assumption to be correct, that all W/T and R/T signalling, even with the TR.9, was capable of being received, logged and correlated by the enemy. The Air Staff was particularly concerned to prevent the enemy from obtaining, during the progress of a raid, indications of the extent of activity from the volume of W/T traffic, and another form of signalling known to be giving away valuable information was the practice of aircraft making frequency checks just before and just after take-off. This practice had four dangers: it indicated the airfields from which aircraft

[1] R/T was used continually in Fighter Command, but in the prevailing conditions the lack of security had, to some extent, to be accepted.

[2] A.H.B./IIH/241/10/32. Bomber Command File 'Security of Wireless Traffic'.

[3] A.H.B./IIH/241/10/32.

were operating and the strength of the effort; it enabled the enemy to signal his intruder patrols that aircraft were taking off from a particular airfield; it enabled him to gauge the most suitable time to put up his interception fighters; and it gave him foreknowledge of the airfields to which his intruders could most usefully be sent to intercept returning aircraft. The Air Ministry issued instructions covering these points, and on 2 December 1941 Headquarters Bomber Command issued a general directive on the restriction of signalling by W/T and R/T.[1] This directive closely followed the existing practice in No. 5 Group. The main points covered by the directive were that every message sent by wireless gave the enemy information of some kind, and for this reason it was clearly important that signalling to and from aircraft should be restricted to the minimum necessary for the success of the mission and the safety of aircraft. Moreover, it was equally important to ensure that all channels were kept free of non-essential traffic, so as to facilitate the passing of urgent operational messages such as recalls and diversions, and improve and speed up communication with aircraft in real and immediate need of assistance. Radar aids to navigation were developed, and use of them materially reduced the need for breaking wireless silence for navigational purposes. At the same time it was decided to introduce the broadcast method on group operational frequencies, and the congestion resulting from large numbers of aircraft acknowledging and being called upon to acknowledge group messages was obviated. Use of R/T for marshalling, however, was not wholly prohibited, and use of R/T for landing control was standardised. An abbreviated pre-flight check procedure was introduced which it was believed gave very little useful information to the enemy. The use of W/T over the target was not re-introduced until the master-bomber technique was evolved in 1943.

The fact that the enemy had only to listen out on the frequencies used by Bomber Command to obtain a great deal of information about operational plans was responsible for the introduction of wireless deception or 'spoof'. In July 1940 it was decided to set up an organisation for that purpose.[2] The deception schemes operated in Bomber Command after August 1941 were simulation of signalling normally carried out by aircraft in the course of night-flying tests, simulation of aircraft returning to base, and spoof transmissions to conceal special operations and movements of squadrons. All involved the use of an attachment to aircraft W/T installations designed to modify the characteristic of the note transmitted when the sets were on the ground so that it sounded like the note transmitted when they were airborne. Effective use of wireless deception was complicated by the changeover from R.1082/T.1083 to T.1154/R.1155, the characteristic note of which was very different. The reduction in air-to-ground signalling brought about by the introduction of Gee lessened the need for deception. A close analysis of daytime signals traffic on H.F. channels revealed that transmission made during daily inspections of equipment and on air tests gave no certain indications of impending operations. To some extent this was the result of instituting a system in which aircraft letters only, and not call-signs, were used for practice transmissions and each aircraft worked with at least one other station in addition to that at its own base. There were occasions, however, when, because of weather conditions, the lack of wireless

[1] A.H.B./IIH/241/10/32.

[2] A.M. File S.5686. An organisation to study enemy radio transmissions was also set up with the object of deducing preparations for operations.

signalling during the day revealed a general stand-down throughout Bomber Command. The use of aircraft letters did not prevent the enemy from obtaining information unless they were frequently changed. A wireless deception organisation was still required, especially in order that the R.A.F. should be able to play its part in inter-Service plans for the liberation of Europe.

One of the principal duties of Coastal Command aircraft was to pass to area combined headquarters the reports and information which they required, especially of enemy forces.[1] Generally speaking, in such instances, the enemy was aware that he was being shadowed, so the question of security could be ignored, but for nearly all other types of operation, W/T and R/T silence were essential. The onus of breaking silence for air-to-ship communications rested with the ship, except in certain special circumstances such as the sighting by aircraft of a U-boat. Reports of this nature were passed direct to the commanders of the convoy on the convoy R/T frequency of 2,410 kilocycles per second.[2] Aircraft engaged on reconnaissance, anti-submarine or escort duties maintained continuous W/T watch on the appropriate frequency. Aircraft on reconnaissance or similar duties, and on convoy escort in the Atlantic, were controlled by the appropriate area combined headquarters, or sometimes by their base station. Very-long-range aircraft operating in the North Atlantic used either Iceland or Liverpool A.C.H.Q., or St. John's, Goose or Gander. When the use of other equipment such as A.S.V. precluded the use of W/T simultaneously, aircraft listened out to the routine broadcast periods, which occurred twice an hour.

Experience during the first winter of the war indicated the magnitude of the problem of assisting operational aircraft to return safely to their bases. Navigation over long distances, particularly at night, proved extremely difficult, and there were frequent fatal accidents caused by errors in navigation or by the inability of crews to find their bases, especially in bad weather. The problem was aggravated by the need for all aircraft in the air to be identified to the fighter defence organisation.[3] The regional control organisation, the first stations for which were completed in 1938, was taken over from Bomber Command by the Air Ministry shortly after the outbreak of war, and was then expanded and reorganised to bring it into closer relationship with the other commands. However, with the expansion that took place in the first two years of war the new system was shown to be inadequate, and in November 1941 a new co-ordinated plan for the landing of large bomber forces in bad weather was introduced.[4] The previous system, in which the task had been undertaken by the individual groups, suffered from a lack of a central control, and frequently led to a situation in which aircraft were kept waiting for instructions, and many crashed through lack of petrol. There were, in addition, many accidents occurring in the vicinity of airfields, such as collisions on the approach and with ground obstructions, taxying accidents, and aircraft under or overshooting when coming in to land, and as a result of a thorough investigation in 1941, standard regulations were formulated for the local control of aircraft, covering their movements from the time of leaving dispersal point until after take-off, and again on their return from the time of handing over to local control till their return to dispersal.

[1] Area Combined Headquarters were located at Gibraltar, Plymouth, Liverpool and Iceland.

[2] Manual of Coastal Command Operational Control, May 1943.

[3] A.M. File S.2704.

[4] A.M. File CS.10503.

By the end of 1942, the facilities necessary for the efficient control of aircraft from the ground were beginning to take shape, and it was clearly established that Flying Control was an essential and permanent feature of the Royal Air Force. But the most important ingredient of an efficient system of controlling aircraft on the ground and in the air, high-quality radio-telephony, was still lacking. The TR.9 was not replaced by the TR.1196 until 1943, and even then the quality of two-way R/T communication left much to be desired. Meanwhile, incidents such as the loss of eight aircraft out of 43 diverted on the night of 26/27 November 1943 continued to focus attention on the need for good speech communication with heavy bomber aircraft. It was not until 1944, however, that standardised fitting of V.H.F. R/T in Bomber Command became practicable, and even then the fitting programme could not be completed for many months.

Improvement of Aircraft H.F. Equipment

On the outbreak of war the standard of aircraft communications achieved was not regarded as satisfactory, and indeed a comparison of operating standards in the Royal Air Force and the *Luftwaffe* showed that general efficiency and manipulation in the R.A.F. compared unfavourably. In the R.A.F., secret call-signs were often compromised, operating signals were misused and sometimes entirely dispensed with, unnecessary transmissions were frequent, a slackness of W/T discipline was evident, and manipulation was generally poor.[1] However, within a few weeks of the outbreak of war a marked improvement in operating and discipline in the R.A.F. was noted, whereas in the *Luftwaffe* a deterioration took place, enabling us to obtain much valuable intelligence. The training and technical knowledge of wireless operators in the R.A.F. was probably better than at any other stage of the war, all operators on operational squadrons being peacetime-trained; thus they were quick to adapt themselves to the needs of war. Again, the comparative size and performance of the two air forces at this time bred caution in the one and carelessness in the other. Similar fluctuations of this kind continued. The influx of war-time aircrew entrants whose training schedules had of necessity been telescoped resulted by 1941 in an extremely low standard of operating in the R.A.F. in all theatres. Then, as these operators gained experience, and as counter-methods of continuation training and incentive were applied, the standard of operating rose steadily.

Another factor affecting the standard of aircraft communications was the equipment in use. In Bomber and Coastal Commands, this comprised the R.1082/T.1083 for W/T, the TR.9D for R/T, and in multi-seater aircraft the A.1134 for inter-communication amongst the crew. The R.1082/T.1083 was an interim general-purpose receiver whose replacement by a more up-to-date apparatus had been planned some years before the war, and the TR.9D operated in the noisy high-frequency bands and had other limitations. The R.1082/T.1083 in particular could not be operated successfully in all conditions by anyone but a highly-skilled operator, and this lent added urgency to the early introduction of the new Marconi equipment.

Introduction of the replacement for the R.1082/T.1083, the Marconi T.1154/R.1155, was not expected to begin until April 1940 because development of equipment to fulfil the operational requirement had not been started at the R.A.E. although specifications had been drawn up in 1935/36. In view of the

[1] A.H.B./IIH/241/10/5. Bomber Command File, "No. 67 Wing Signals arrangements including R.D.F."

urgent need of this improved equipment, it was arranged for the firm of Marconi to provide fitting parties, under the supervision of No. 26 Group. However, production of the equipment did not begin until August 1940, when trial installations were made by the firm in a Wellington, Whitley, Hampden and Blenheim. It had been found some time previously that the electrical power supply originally provided in these aircraft was insufficient to supply the input required by the new set, and it was decided that either a larger or an additional generator must be provided. However, since it was anticipated that supplies of the new generator could not be made available in time for the T.1154/R.1155 installation programme, it was decided as a temporary measure to provide an additional accumulator to give the power required, until such time as the extra generator could be fitted. Unfortunately, when the first installations were tested it was found that the accumulator was unsatisfactory and that the radio equipment could only be installed and used when the larger or additional generator was provided.[1] It was therefore necessary to arrange fitting parties to fit an additional generator at the same time as the new Marconi equipment was installed.

By November 1940, the additional electrical supply in Whitleys, Wellingtons and Hampdens had been arranged, and fitting began, but installation in the Blenheim was still held up as the Bristol Aeroplane Company had been unable to supply the fitting party or fittings to install the additional generator. Even more disturbing was the situation with the new heavy-type bombers, the Stirling, Halifax and Manchester; they were leaving the aircraft production line wired for the old layout.[2] For the rest of the winter 1940/41 the majority of aircraft in Bomber Command, and nearly all the aircraft in Coastal Command, were equipped with R.1082/T.1083, and there were occasions when heavy losses in Bomber Command were attributed largely to the failure or inadequacy of the existing W/T equipment, and to the continued absence in some groups of a regional control organisation. It was believed, in particular, that eleven Wellingtons which were lost on the night of 11/12 February 1941 could have been guided in to airfields which were not unserviceable through bad weather if they had had efficient wireless facilities. Everything was being done to speed up the general introduction of T.1154/R.1155, and indeed at the time progress of production and installation was regarded as satisfactory; 1,000 sets had been delivered and a further 1,500 were due for delivery in March. However, Air Ministry satisfaction was not shared by the C.-in-C., Bomber Command, who regarded the situation not from the aspect of the numbers of new equipments being produced but from the numbers of operational aircraft equipped. On 22 February 1941 only 60 Hampdens had been completed, of 272 operational Wellingtons only 15 were fitted, about 25 per cent of Whitleys were equipped, and in nine Blenheim squadrons not one aircraft was fitted. The situation had greatly improved by the winter of 1941/42, but it was not until 1943 that the last R.1082/T.1083 was replaced in Coastal Command.[3]

A large number of different versions of the basic T.1154/R.1155 installation were eventually produced to meet different requirements for frequency coverage and containers, and to meet manufacturing problems such as shortage of

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[1] A.H.B./ID/2/125. C.I.D. Home Defence Committee Reorientation of the Air Defence system of Great Britain. Memo. by the Home Defence Sub-Committee of the C.I.D.

[2] A.H.B./ID/2/125.

[3] Coastal Command Signals Review, Volume I, No. 3, March 1944.

materials and tooling difficulties. By August 1944 the number of variants had been reduced to:—

T.1154 H — for all Halifax and Sunderland aircraft as well as for types of aircraft which required aluminium container versions to lessen interference with the compass.

T.1154 L — for air/sea rescue marine craft and wireless trainers.

T.1154 M — for general use.

R.1155 A — for Halifax bomber aircraft.

R.1155 F — for all bomber aircraft other than Halifax and for types of aircraft which required aluminium container versions.

R.1155 L — for general use (aluminium container version of R.1155 N)

R.1155 N — for general use except in bomber aircraft.

To meet the requirement for a general purpose installation of the same dimensions as T.1154/R.1155 but much lighter, and with an overall performance approximately equal to that of T.1154/R.1155 but operating on a considerably reduced power input, the T.1528/R.1529 installation was developed. The power input was effectively reduced by employing a single power unit for H.T. supply to both transmitter and receiver and by connecting all valve heaters (both transmitter and receiver) in a series-parallel arrangement, supplying them from the aircraft 24-volt batteries through a carbon pile regulator. Transmitter design was based on the T.1154 H although the circuit differed considerably, whilst the receiver was basically the same as the R.1155 L. Service trials were completed by December 1944. However, although the installation fulfilled requirements satisfactorily the concensus of opinion was against its gradual introduction at that stage of the war because the advantages gained in reduced input power and weight did not compensate for the fact that special training in its operation would have to be given and a new fault-finding technique would have to be evolved and learnt. Further development was therefore stopped.[1]

A decision to install R/T equipment in all R.A.F. aircraft was made in 1936, but the demands of Fighter Command delayed general introduction of the TR.9. R/T was thought to be of use in bomber aircraft largely for the tactical control of formations by the leader and to assist in the concentration of fire-power. Its use for airfield control was not at first considered but by the outbreak of war duty pilots at many R.A.F. airfields were using H.F. R/T to control aircraft movements although no standard procedure existed until 1941.[2] Because of Admiralty insistence on the maintenance of wireless silence during fleet exercises and operations before the war, when reliance was placed on visual signalling methods, no R/T communication equipment had been specifically designed for aircraft of Coastal Command. Developments to meet the requirements which arose soon after the war began were consequently made on an *ad hoc* basis. Complications were added by the many different types of aircraft with which the command was armed, fitted with different types of wireless equipment, both British and American. It was soon found that the efficacy of anti-U-boat escorts operating with convoys was considerably lessened by dependence on Aldis lamp communication, and escort vessels were equipped with H.F. R/T equipment. The convoy frequency, 2,410 kilocycles per second, had to be used,

[1] A.H.B./IIE/44.

[2] An aircraft installation was usually adapted for use on the ground.

and was not very suitable for R/T communication.[1] TR.9 equipment, suitably modified, was installed in Coastal Command aircraft, but was far from satisfactory for air-to-ship communication. The technical limitations of low ranges, poor quality of speech, high noise to signals ratio and frequency congestion were increased by the lack of understanding of each others' difficulties which sprung from inexperience of operating conditions, for there had been no opportunity for practising air-to-ship R/T communication. The inadequacy of the TR.9 installation was emphasised in the summer of 1943, when the U-boat Command began the use of group sailing tactics in the Bay of Biscay. Once a group had been located the sighting aircraft orbited beyond gunfire range until joined by reinforcing aircraft. The sighting aircraft then became responsible for controlling the ensuing attack, and for this purpose effective air-to-air R/T communication was essential. Because the performance of the TR.9 was inadequate many promising anti-U-boat attacks were spoilt by lack of co-ordination.[2] The efficacy of aircraft, and particularly of aircraft radar, was being lessened to some extent by the inefficiency of aircraft communications equipment, but by that time the TR.1196B and similar American equipment was being installed in Coastal Command. The TR.1196 made available four spot frequencies, with selection by remote control, in the band 4·8 to 6·7 megacycles per second.[3] The transmitter and receiver were crystal-controlled (eight crystals per installation) and worked from a self-contained power unit, the total input being approximately 60 watts from the aircraft supply. Its introduction considerably improved the efficiency of aircraft communications, in spite of the inherent limitations of H.F. R/T, and early in 1944 one convoy commander reported '. . . from experience of last four months . . . R/T communications with Coastal Command aircraft have been excellent and difficult to improve . . .'[4]

Development of V.H.F. R/T System—1935 to 1939

The development of V.H.F. equipment was formally added to the R.A.E. development programme in January 1935, when at a wireless development conference it was stated that research should be initiated and '. . . it seems possible that a practical set should be forthcoming in five years time . . .'[5] Transmitters and receivers for aircraft and ground use were to be developed and consideration was to be given to direction-finding on the V.H.F. band. Because of the urgent requirement for improved R/T performance in fighter aircraft, longer ranges being required for homing and vectoring than could be provided with the H.F. equipment in use, the development programme was amended in 1936 so that the whole fighter R/T organisation could be made to work in the 100 to 120 megacycles per second frequency band. It became possible to apply considerably more resources to the development of V.H.F. equipment. Suitable personnel were recruited and progress was made in the development of measuring equipment, the lack of which had retarded progress in the previous years. However, some time elapsed before crystal-controlled transmitters and superheterodyne receivers were considered to be practicable

[1] Extra coils had to be provided for the R.1082/T.1083 installation.

[2] *See also* A.H.B. Narrative 'The R.A.F. in Maritime War'.

[3] About 800 TR.1196 installations were modified to meet Transport Command requirements and were known as TR.1518.

[4] Coastal Command Signals Review, March 1944.

[5] A.H.B./IIE/249.

and considerable effort was expended on less efficient types of equipment which were inadequate for the complete communications system required. The R.A.E. was made responsible for the specifications of buildings, their internal layout, and their inter-station line communications as well as the design and development of radio units and the selection of sites. This was probably the first occasion on which the R.A.E. radio engineering staff had been given complete responsibility for planning in addition to technical development, and early development of the V.H.F. R/T system was in that respect analogous to that of R.D.F.

In the meantime the shortcomings of the H.F. R/T communications system were becoming more obvious. Some improvement was effected by the introduction of crystal control in the TR.9F but the system was quite inadequate. Apart from the increase of serious interference, especially at night, on the H.F. band, the number of communication channels made available was insufficient, and the ease with which transmissions could be intercepted at long ranges was giving rise to anxiety.[1] The interference and vulnerability to interception were unavoidable because of the fundamental properties of the ionosphere at the frequencies in current use, but the use of very high frequencies offered some alleviation. It was known that wireless waves of very high frequency normally penetrated the ionosphere and were not deflected by it so that long-range jamming was not possible. It was expected that the range of communication on V.H.F. would be limited to the optical horizon and, although experience showed that anomalous conditions which resulted in greater ranges being obtained could exist, in practice the expectation was broadly realised. More channels were required partly because of the expansion of the fighter organisation and partly because of changes in the technique of fighter control made necessary by the successful development of R.D.F.

With the growth of tension in the international situation the need for improvement of fighter communications was emphasised; and the improvement could not be made without the full-scale introduction of V.H.F. R/T. Development of a complicated V.H.F. R/T system was bound to take a comparatively long time and consequently the possibility of suitable alternatives was examined. When information was received, early in 1938, that the Royal Netherlands Air Force had been operating a V.H.F. R/T system for some eighteen months to two years, two signals officers were sent to Holland to inspect it at the invitation of the head of the wireless section of the air force. They reported that '. . . the V.H.F. R/T installation is a sound, practical, working proposition although no attempt to introduce any great measure of advanced technique has been made . . .'[2] However, when purchase of an installation was suggested, it was pointed out that the estimate of five years made in 1935 was for the provision of a complete V.H.F. R/T system for Fighter Command, including ground stations, aircraft installations and direction-finding facilities. The difficulties involved in the provision of 80 adjacent R/T channels were emphasised by the Director of Communications Development, who added that, at the time when research at the R.A.E. was begun, equipment to meet the requirement could not have been produced by any organisation in any country. The Dutch equipment was very similar to that which the R.A.E. or any competent radio firm could have produced some five or six years earlier; it could not provide the number of

[1] A.H.B./IIE/249.

[2] A.M. File S.44756. The officers were Wing Commanders O. G. Lywood and R. S. Aitken.

channels or the stability and selectivity required by the R.A.F.[1] At that time V.H.F. R/T development at the R.A.E. had reached the stage where '. . . the technical features of a crystal-controlled ground transmitter (TX.62) to include instantaneous electrical remote control to any of six spot frequencies had been established, and the transmitter was being made in the workshops. A complete aircraft transmitter/receiver (TRX.25), incorporating electrical remote control to any of four spot frequencies, the transmitter being crystal controlled and the receiver being provided with automatic fine-tuning, is being made . . . single-frequency prototypes . . . are now in operation both in the air and on the ground . . .'[2]

Perhaps partly as a result of the stimulus given by the investigation to progress with development, the Director of Signals was able to inform the C.A.S. in January 1939 that a substantial proportion of Fighter Command, eight sectors and sixteen squadrons, could be equipped with V.H.F. R/T by September 1939 if installations slightly inferior to those originally planned and initially produced on a limited scale were acceptable to the Air Staff.[3] The proposal was not without an element of risk, since it was always possible that war might begin before the changeover from H.F. to V.H.F. had been completed, and the resultant difficulties were obvious. It meant going ahead on a considerable scale with equipment which had not been given Service trials, but the risk was minimised by the design of the aircraft installation. Its shape, size and means of fitting in aircraft were to be similar to those of the TR.9 so that, if the worst came to the worst, squadrons could change from V.H.F. to H.F. or H.F. to V.H.F. R/T equipment in about ninety minutes once the necessary wiring, generating and voltage control systems had been installed in the aircraft. The scheme, which had been formulated with the aid of the Director of Communications Development, was summarised by the A.C.A.S. for the C.A.S. as '. . . the question at issue is whether we should go straight away for V.H.F. in our fighters. As you know the great advantage of V.H.F. is that it cannot be jammed, whereas there would be no great difficulty in jamming our present fighter R/T sets. We thought that it would take several years to produce a satisfactory V.H.F. set. So much so that, until recently, we were contemplating going into production on an improved model of the present fighter R/T set.[4] . . . Thanks however to strenuous efforts on the part of the Director of Communications Development and the R.A.E. it now appears that we can get into production straight away on a hand-made V.H.F. set which, in the opinion of the D.C.D., has every chance of being successful. This means that we shall be able to get 200 to 300 fighter aircraft equipped with V.H.F. sets by September of this year. The Director of Signals proposes to build up the V.H.F. R/T ground organisation alongside the present organisation and to arrange for the V.H.F. equipment to be interchangeable with the present R/T sets, so that even if V.H.F. is not so successful as we anticipate we shall still have the present organisation and equipment to fall back on . . . The scheme is of course a bit of a gamble but . . . I strongly

[1] The Dutch system worked in the 60 to 70 megacycles per second frequency band. The transmitter was a modulated self-oscillator with an output of 20 watts. The receiver was super-regenerative with six pre-set frequency spots. Crystal control was not used.

[2] A.M. File S.44756.

[3] Sectors to be equipped were Debden, Biggin Hill, Hornchurch, North Weald, Duxford, Wittering, Catterick and Digby.

[4] An H.F. R/T installation was being produced by the Standard Telephones and Cables Company, designed by the firm with modifications added by the R.A.E.

recommend that you approve these proposals. . . .'[1] The C.A.S. replied that he was satisfied that the proposals were sound and directed that their fulfilment was to be treated as a matter of first importance in view of the international situation. '. . . If you are held up by the "machine" please let me know . . .'

The V.H.F. R/T installation plan was divided into two stages. In Stage I, which it was intended should give place to Stage II in May 1940, the aircraft installation was the TR.1133, and consisted of a crystal-controlled transmitter and a superheterodyne receiver with automatic fine-tuning; four spot-frequencies were available. The ground transmitter was the T.1131, a single-channel master-oscillator capable of rapid frequency-change, and the ground receiver was the R.1132, a superheterodyne with single-knob tuning. In Stage II all Fighter Command aircraft were to be equipped with TR.1143, in which the receiver was crystal controlled as well as the transmitter. The ground receiver was also to be crystal controlled and the output power of the ground transmitter was to be increased.

Rapid progress was made with Stage I. By July 1939 all sites had been obtained, buildings were to be completed by mid-August, and the provision and erection of masts had been almost completed. Delivery of equipment from the manufacturers began in August. Suitably modified Spitfires were due to leave the aircraft factories in mid-August at the rate of 11 or 12 per week, but delivery of the first modified Hurricane before the end of October could not be promised; it was expected that the rate of delivery would then be 5 per week rising to 12–15 by the end of the year. Since 10 of the 16 squadrons which were to be equipped with the TR.1133 were armed with Hurricanes this raised a serious problem.[2] The question of aircraft modifications gave rise to another appeal to the Chief of the Air Staff. In August 1939 the Directorate of Communications Development asked that the new, modified aircraft should be issued to all the squadrons which were to be equipped with V.H.F. R/T and their old aircraft withdrawn. On the grounds that such an arrangement would result in another period of re-equipping fighter squadrons the request was strongly opposed by the A.M.S.O., who contended that approval for the introduction of V.H.F. equipment had been given on the assumption that there would be no aircraft modifications because the equipment would be interchangeable with the TR.9 installation; he recommended that the modified aircraft should be put into reserve and not into front-line squadrons.[3] The A.C.A.S. pointed out that the interchangeability could not be construed to mean that there would be no aircraft modifications; the Director of Signals had stated that there would be some in his original proposals. The C.A.S. appreciated the point of view of the A.M.S.O., but as the matter was of prime importance to effective air defence of the country he ruled that Fighter Command was to be provided with modified aircraft as quickly as possible.

Meanwhile good reports had been received of V.H.F. R/T equipment being used by the French Air Force and it was thought possible that the technique used in the French equipment, developed largely by radio firms to the specification of the French Air Ministry, was far in advance of that used in the equipment being manufactured for the R.A.F. However, the D.C.D. informed the C.A.S. in August that he had made a detailed investigation of the sets in December 1938 and again in May 1939 and had ordered, for trial purposes, one

[1] A.M. File S.44756. [2] A.M. File S.49038. [3] A.M. File S.49038.

D/F ground installation, which was the only equipment which seemed likely to have any advantages. '. . . As I have frequently informed the Director of Signals, he could have had a V.H.F. R/T set as bad as the Dutch and French sets years ago, but his own requirement specification and our technical standard alike very properly excluded it from proposals for introduction . . .'[1]

Service trials of TR.1133 took place at Duxford on 30 October 1939, with six Spitfires of No. 66 Squadron. The results exceeded expectations. An air-to-ground range of as much as 140 miles was obtained at 10,000 feet, and an air-to-air range of over 100 miles. The Director of Signals reported that '. . . there can be no doubt that even Mark I V.H.F. equipment opens up a completely new chapter of aircraft R/T communication. Telephony was in every case far better than anything previously heard and the whole of the ground arrangement as laid out by the R.A.E. seemed to fit completely the operational requirement. Direction-finding, both for plotting and homing, was instantaneous and exceedingly accurate. . . . It is a matter of great satisfaction and reflects the greatest possible credit on all concerned, particularly No. 10 Department of the R.A.E. who have evolved in a matter of ten months a completely new scheme, which previously had taken four or more years to produce . . .'[2] A few days later the Chief of the Air Staff approved the general introduction of V.H.F. R/T in Fighter Command. An important consequence was that the decision to limit the hand-made TR.1133 to Stage I was changed. TR.1143 was not yet ready and TR.1133 was put into quantity production.

V.H.F. R/T in Fighter Aircraft

Once the Chief of the Air Staff had approved the general introduction of V.H.F. R/T in Fighter Command in October 1939 rapid and effective action was taken to implement the sector station installation programme.[3] By the beginning of December Headquarters Fighter Command was able to inform the Air Ministry of the requirement and sites for ground stations. It involved the installation of 20 new stations together with an increase in the equipment of the existing eight stations. Sixteen of the new stations (11 of them sector stations) were to be completely fitted and tested by the end of September 1940 and the other four by the end of the year. It was decided that two types of mobile ground equipment was required; one using the T.1131 for homing, direction-finding, and relay station purposes, and one using the aircraft installation TR.1133 for ZZ landings. The former was to be provisioned on the scale of one per sector station, 15 for relay stations, and 15 for satellite stations, spares and training; the light, mobile equipment was required at every Fighter Command airfield. Installation of the 20 new stations was completed by September 1940, but in the meantime more sectors had been added to the command and the requirement for equipment was consequently increased. In June 1940 Headquarters Fighter Command requested that all R.D.F. stations affiliated to sector stations should be equipped with single-channel V.H.F. R/T. V.H.F. R/T equipment was also installed in G.C.I. stations when they began operating early in 1941; effective close control of night fighters required installation in the aircraft of 8-channel V.H.F. R/T.

[1] A.H.B./IIE/249. One year later the French Air Force found that their V.H.F. R/T system did not provide sufficient communication channels, and asked for supplies of R.A.F. equipment.

[2] A.M. File S.44756.

[3] Installation of eight sectors as specified in the original plan was completed in January 1940.

Production in quantity of aircraft installations was complicated by delays in the development of TR.1143. Provisioning action for aircraft equipment was taken in November 1939 but it was not then possible to forecast when TR.1143 would be ready for quantity production. Consequently, from a provisioning aspect, no distinction was made between TR.1133 and TR.1143. The total requirements were calculated and requisitions were raised to cover a definite number of TR.1133 installations and an additional number of equipments which were to be TR.1133 or TR.1143, according to the progress made towards completion of development of TR.1143. The total number of sets originally requisitioned was 13,260, to be delivered by the end of March 1941.[1] In July 1940 deliveries from the first contract for 6,000 TR.1133 placed with the General Electric Company were expected to begin in the following month, and completion of the contract by March 1941 was anticipated. Production of TR.1143 was evidently not going to begin in time and therefore a contract was placed for an additional quantity of 5,200 TR.1133. By the end of 1940 the total requirement had increased and requisitions were raised for another 8,775 equipments. The continued delay in reaching the production stage with TR.1143 resulted in a proposal being made early in 1941 to secure some of the benefits of the newer design by providing a crystal-controlled receiver unit, R.1225, for use with the transmitter unit of TR.1133; the new combination eventually became TR.1133 G and TR.1133 H.[2] Incorporation of the new receiver considerably extended the number of possible frequency channels beyond the 86 of TR.1133. Contracts were placed for 5,000 receivers R.1225 and were later increased to cover the period between the end of production of TR.1133 and the delivery of TR.1143.

By May 1940 installation of hand-made TR.1133 had been completed in eight squadrons.[3] During that month many fighter aircraft were lost in air battles during the evacuation from Dunkirk, and on 26 May 1940 the squadrons were ordered to change back from V.H.F. R/T to H.F. R/T, an eventuality which had been foreseen in January 1939. The A.O.C.-in-C. Fighter Command informed the Air Ministry that '. . . I have found it necessary to suspend indefinitely the further use of V.H.F. equipment by fighter aircraft. I appreciate fully, and I know my views will be shared by the Air Ministry, that to have to abandon the use of our most successful form of fighter communications at the present time is a deplorable necessity. The result must be to reduce the operational efficiency of this command. The necessity which has forced me to resort to such drastic action is due entirely to inadequacy of supplies and the need for conserving our available reserves so that the equipment shall be on hand for use in its proper sphere and to the best advantage when the occasion demands. At the present time I am required to operate fighter patrols over the Channel and parts of France and Belgium from bases in the south-east of England: losses are unavoidable and, apart from the initial issue of 25 sets of V.H.F. equipment to each of the eight squadrons which have been fitted up to date, and also 40 additional sets suitable for Hurricanes only, I am informed that no further equipment of this sort will become available until the late summer. A further complication which arises is due to the fact that I must

[1] 7,680 were to be 12-volt and 5,580 24-volt installations.

[2] Because the receivers in TR.1133 were not crystal-controlled they were subject to frequency shift due to temperature variations. It was therefore desirable to allow as much as 450 kilocycles per second separation between channels in the band covered, 100 to 120 megacycles per second, compared with the 250 kilocycles per second separation in TR.1143.

[3] Nos. 41, 54, 66, 611 (Spitfire) and Nos. 17, 32, 56, 213 (Hurricane).

maintain complete flexibility in the operation of all my squadrons under the present exceptional conditions. In some cases it is necessary to operate composite squadrons, when it is obvious that the aircraft concerned must be fitted with the same type of apparatus to permit of air-to-air communication. Although every squadron equipped with V.H.F. equipment is in possession also of complete H.F. equipment, it is not practicable for a squadron to keep changing from one type of equipment to another, neither is it practicable to maintain proper ground organisation. By reverting to H.F. R/T communication throughout the command my Chief Signals Officer considers it probable that he will be able to compete with all likely communication problems but the continued use of the admixture of H.F. and V.H.F. is unworkable . . . '[1]

Deliveries of TR.1133 from quantity production began, as had been anticipated, in August 1940, when Headquarters Fighter Command decided to restart the changeover to V.H.F. R/T, beginning with squadrons based at stations where ground equipment and suitably trained personnel were available.[2] It was emphasised that approval for the changeover to begin immediately was given only on the assumption that the manning situation at the selected stations was such that both V.H.F. and H.F. R/T could be operated in conjunction, and H.F. R/T equipment was to be kept in a state of readiness. Although by the end of September 1940 sixteen single-seater fighter squadrons and six Blenheim fighter squadrons had been equipped, the TR.1133 installation programme was not sufficiently far advanced to enable Fighter Command to take full advantage of the superiority of V.H.F. over H.F. R/T, but its use by even a limited number of squadrons was of considerable assistance to pilots and controllers especially at long ranges.[3] Thereafter Fighter Command demands for V.H.F. R/T equipment rapidly and considerably increased and large-scale production and installation programmes were put in hand, those for TR.1143 beginning in 1942.

In order that ground controlled night fighters equipped with A.I. could be made more effective, eight readily available V.H.F. R/T communication channels were required. An installation based on the design of TR.1143 but with twice the number of channels was therefore developed and was known as TR.1430. Until it was ready for operational use night-fighter aircraft were equipped with a twin-TR.1143 installation. By March 1944, when 100 TR.1430 equipments had been produced, the requirement had risen to 12 channels, so the TR.1430 was installed retrospectively in aircraft of three night-fighter squadrons as a replacement for one of the TR.1143 sets. When deliveries from quantity production began, twin-TR.1430 installations were fitted on the aircraft production lines in Mosquito and Welkin night-fighter aircraft thus providing them with 16 readily available communication channels.[4]

The advent of high-performance single-seater day-fighter aircraft called for a new design of V.H.F. R/T equipment, and the light-weight TR.1464 installation was developed. Compared with the TR.1143 it represented an overall saving in weight of 50 pounds and provided eight channels. Flight trials were undertaken in March and April 1944 when air-to-air ranges of 175 miles at 400 feet and air-to-ground (T.1131/R.1132) ranges from 90 miles at 2,000 feet to 150 miles

[1] A.M. File S.44756. *See also* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

[2] Nos. 19, 41, 54 (Spitfire) and 17, 32, 46, 56, 229 (Hurricane).

[3] *See also* Royal Air Force Signals History, Volume V: 'Fighter Control and Interception'.

[4] A.H.B./IIE/44.

at 8,000 feet were obtained. Without waiting for type approval and full Service trials production of a limited number of equipments was begun in August 1944 for installation in Meteor aircraft. A new problem was encountered when it was discovered that the whine peculiar to jet aircraft could be transmitted through the V.H.F. R/T installation. This was serious since it might provide the enemy with important information. The difficulty was to some extent overcome by inserting a filter in the microphone circuit but it was only a partial solution of the problem as the noise was still distinguishable unless the pilot's oxygen mask fitted perfectly.[1]

The Royal Navy first became actively interested in the R.A.F. V.H.F. R/T system in 1941. Convoys sailing off the east coast were then being provided with fighter escort operating under the normal R.A.F. control system. It was found that fighter pilots were not always aware of the position of German aircraft which could, however, be seen from the ships.[2] It was therefore suggested that the escort surface vessels should be equipped with V.H.F. R/T so that direct communication with air escorts would be possible. An experiment with an installation in a cruiser, consisting of T.1131 and R.1132, was very successful. Accordingly all escort vessels of east-coast convoys were equipped with V.H.F. R/T but owing to the limited space available TR.1133 was used. In 1942 V.H.F. equipment was installed in two cruisers engaged on convoy escort duties in the Mediterranean so that they could control the operations of escorting R.A.F. fighters. The results encouraged the Naval Staff to arrange for the installation of V.H.F. equipment for fighter control in all major ships. In December 1943 trials were begun of installations consisting of adapted T.1131 and R.1132 equipment in aircraft carriers. The results obtained were so satisfactory that it was decided that all Fleet Air Arm fighter aircraft should be equipped with suitable V.H.F. R/T.[3]

V.H.F. R/T in Bomber and Strike Aircraft

The possibility of using V.H.F. R/T in Bomber Command aircraft for local flying control was first considered in March 1940, and provision of equipment working in the 126 to 146 megacycles per second frequency band was proposed. By December 1940 work on the design of TR.1226, to be interchangeable with TR.1143 but with a different frequency coverage, for installation in Bomber Command aircraft had begun.[4] However, experience with TR.1133 in Fighter Command had shown that R/T ranges considerably in excess of optical ranges were frequently obtained and it was feared that such occurrences would mar the effectiveness of a V.H.F. Darky system. In any event Bomber Command would be faced with the necessity for a more elaborate organisation than it could then deal with. The position was further complicated by the large demands for V.H.F. equipment made by Fighter Command and the consequent absorption of production capacity to meet them. In addition, the most urgent Bomber Command requirement for V.H.F. R/T in 1941 was for day bombers of No. 2 Group.

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[1] To meet a requirement for V.H.F. R/T in flying-boats of A.C.S.E.A. in July 1945 trial installations of TR.1464 were begun and arrangements made for general fitting to take place retrospectively and on aircraft production lines.

[2] *See also* A.H.B. Narrative "The R.A.F. in Maritime War".

[3] An adaptation of SCR.522 (TR.5043) was installed in H.M. destroyers.

[4] Also on the design of T.1227 and R.1228 for use on the ground.

Installation of TR.1133 in selected aircraft of No. 2 Group so that they could communicate with fighter escorts was first proposed by the A.O.C.-in-C. Fighter Command in August 1941, and early in 1942, the supply of TR.1133 still being very limited, two Boston and three Blenheim squadrons were provided with enough equipment to enable aircraft of formation leaders only to be fitted. However, in practice it was found that there were serious drawbacks arising from the fact that the bomber leader when using V.H.F. R/T was unable to communicate with other bomber aircraft in his formation or with his crew. On 20 June 1942, Headquarters Bomber Command and Headquarters Fighter Command asked for the fitting of all No. 2 Group aircraft, then Bostons and Venturas, with TR.1133 and amplifier A.1219.[1]

Meanwhile, development of the TR.1356, a small two-channel V.H.F. transmitter/receiver, had reached a stage at which it was necessary to decide on the uses to which it was to be put and the qualities which would be required. A conference was therefore held at the Air Ministry on 14 August 1942 to discuss these points, with particular reference to the use of TR.1356 by No. 2 Group. However, it was agreed that, since aircraft of No. 2 Group were to be employed almost entirely under the operational control of Headquarters Fighter Command, they would need to be equipped with TR.1133 and subsequently TR.1143. At the same meeting it was decided that medium and heavy bombers would be unlikely to operate in conjunction with fighters and that installation of TR.1356 in them was unnecessary.

On 1 October 1942, the Air Ministry made final proposals for the fitting of aircraft in No. 2 Group, which by then included Mosquitos, Bostons, Venturas, and Mitchells. The two-way W/T installation was to be discarded, and V.H.F. R/T and Gee were to constitute the basic radio aids to navigation. The proposals were at first agreed by Headquarters No. 2 Group who, however, on 19 December 1942 decided not to discard the installation of two-way W/T in aircraft manufactured in the U.S.A., preferring for various operational reasons to keep the W/T facility at the expense of Gee.[2] Gee, however, was retained in the Mosquito on account of its greater radius of action. W/T equipment in the Boston, Ventura and Mitchell aircraft was American. The V.H.F. R/T fitting programme allowed for the fitting of Mosquito and Boston aircraft by 1 March 1943 and Ventura and Mitchell aircraft by 1 April 1943. No comprehensive ground organisation could be allotted to No. 2 Group because of the acute shortage of frequencies, and as a result frequencies and organisations were shared with other commands. There were considerable technical difficulties in the employment of British V.H.F. equipment side by side with American W/T installations, especially in the Mitchell, but these were overcome by various compromises.

It had been realised by the U.S.A. authorities early in the war that the R.A.F. V.H.F. R/T system was considerably in advance of anything then available to them. Consequently in 1942 one of the first TR.1143 prototypes was sent to the U.S.A., where the basic scheme was copied, details being modified to suit American components and methods. By agreement with the U.K. authorities the new set, SCR.522 (TR.5043), was made mechanically and electrically interchangeable with TR.1143, but it was arranged to have increased frequency coverage, from 100 to 156 megacycles per second, to meet operational requirements. It was supplied to the R.A.F. in considerable quantities to supplement TR.1143 production in the U.K.[3]

[1] A.H.B./IIH/241/10/38(A). [2] A.H.B./IIH/241/10/38(A). [3] A.H.B./IIE/249.

The need for better quality R/T in bomber and Coastal Command aircraft made it necessary to consider the general introduction of V.H.F. R/T in heavy and medium bombers and possibly general reconnaissance and training aircraft. There were three possible courses of action; the employment of TR.1143 (100 to 124 megacycles per second), the employment of SCR.522 or a similar installation (100 to 156 megacycles per second), or the development of a new installation which would meet all requirements. One main factor to be considered in the choice of a method was availability of frequencies. Until the summer of 1943 the frequency band 124 to 146 megacycles per second had been reserved for possible V.H.F. R/T equipment in aircraft other than fighters. The claims of the Fleet Air Arm and the United States Army Air Force had, however, to be met, and frequencies were allocated as :—

100 to 124 megacycles per second :	Royal Air Force.
124 to 128 megacycles per second :	Fleet Air Arm fighters.
128 to 131 megacycles per second :	Fleet Air Arm fighters (at sea only).
131 to 135 megacycles per second :	Fighter reconnaissance aircraft when SCR.522 installed in Mustang aircraft.
135 to 145 megacycles per second :	U.S.A.A.F. bombers and fighters.

Channel requirements of home commands were considered to be :—

Fighter Command	110
Bomber Command	120
Coastal Command	11
Tactical Air Force	11
Total	252

Receiver components of TR.1143 and SCR.522 were not capable of discrimination between signals less than 180 kilocycles per second apart. Consequently TR.1143 provided only 133 frequency channels in the 100 to 124 megacycles per second band. The General Electric Company was developing a multi-channel frequency-modulated installation which provided 288 channels, with 90 kilocycles per second spacing, in the 124 to 150 megacycles per second band. An experimental version of the equipment was given flight tests in July 1943. It was possible to modify it so that it would make available 266 channels in the 100 to 124 megacycles per second band, but extension of the frequency coverage up to 130 megacycles per second was suggested in order that Fleet Air Arm requirements might also be covered.

When considering its adoption it was possible to visualise its introduction into Service use in two stages. The first was retrospective installation in Fighter Command. This would be necessary as Fighter Command was already using all the channels available at 180 kilocycles per second spacing in the 100 to 120 megacycles per second band. When all aircraft had been equipped the command could be allotted the band from 100 to 110 megacycles per second in which the requirement of 110 channels could be met with 90 kilocycles per second separation. The second stage would be to install the equipment in aircraft of Bomber Command, Coastal Command and the Tactical Air Force. The Bomber Command requirement of 120 channels could be met between 110 and 121 megacycles per second, that of Coastal Command between 121 and 122, and that of the Tactical Air Force between 122 and 123 megacycles per second. This would leave 123 to 130 megacycles per second, approximately 77 channels, for the Fleet Air Arm.[1]

The G.E.C. equipment offered advantages other than a greater number of channels. A simple controller in the pilot's cockpit enabled remote selection to be made of all available channels. The remote control was achieved by means of two click-stop dials. The stops on the dials were given letters of the alphabet. Frequencies were selected by turning the dials to a particular combination of two letters. The installation employed four crystals which were the same in every set so that provisioning of crystals was not complicated, and since the crystals were permanent fixtures and channel selection automatic there was no need to set up frequencies before flight. However, there were certain research problems still to be overcome in the frequency modulation technique, particularly with the close channel spacing envisaged, and since the technique was very much of an unknown quantity, especially in connection with aircraft installations, there was a great element of risk in changing over to it during wartime. The chief advantage of frequency modulation over amplitude modulation was its improved signal to noise ratio, but a disadvantage was that direction-finding was difficult and the incorporation of beam approach facilities in a frequency-modulated receiver might not be possible.

In July 1943 the operational requirements of home commands were reviewed. In Fighter Command TR.1143 was meeting requirements satisfactorily except that the need for more channels was ever-increasing, and until more could be made available the flexibility of operations was becoming somewhat constricted. The problem of crystal distribution was already complicated and it was fairly certain that in the near future night fighters would require from 12 to 16 channels and day fighters 8, to be selected at will. In Coastal Command there were two separate requirements, one for general reconnaissance aircraft and the second for strike aircraft. The major need in reconnaissance aircraft was long-range R/T communication with escort vessels; a range of 100 miles at low heights was required, and this was not likely to be obtained with V.H.F. equipment. Another need was for R/T control in co-ordinated attacks against U-boats for which an air-to-air range of 10 miles was essential.[2] The main requirements for strike aircraft were good tactical control, R/T communication with fighter escorts, and long-distance W/T communication with base. The first two were being met with TR.1143 but it was considered that eight channels, to be selected at will, would ultimately be needed. Strike aircraft might also be employed on controlled interception of E-boats and other light surface craft in which case they would be placed under the control of the appropriate fighter organisation.

Bomber Command required an R/T system for airfield control at ranges up to 75 miles when aircraft were at 3,000 feet, short-range air-to-air R/T for formation control, R/T communication between bombers and fighter escorts, and air-to-air R/T at ranges of 30 to 50 miles for the new Master Bomber

[1] A.H.B./IIE/44.

[2] In 1943 development of an airborne R/T relay station was begun in order that the ground-to-air range of V.H.F. R/T might be extended. The project was considered to be of particular value for increasing the range of communication with low-flying aircraft; effective range between ground stations and aircraft at 500 feet was normally only about 30 miles. To overcome the limitations imposed by the use of very high frequencies the airborne relay station was equipped with a combination of TR.1196 and TR.1143. TR.1196 was used for communication between relay aircraft and ground and TR.1143 between relay aircraft and forward aircraft.

technique.[1] Successful application of this new technique was dependent upon efficient R/T communication between the master bomber and aircraft of the main force when in the target area. The technique was applied in two forms, one in which the master bomber exercised only loose control over the main force, limiting his instructions to those necessary to ensure that the attack was carried out as planned, and a second and more rigid system in which the master bomber assumed direct and close control of the main force, and varied the method and/or time of attack at his discretion. Various methods of putting the technique into practice were being tested. The main ones were use of T.1154 in the controlling aircraft and R.1155 in the other aircraft for R/T communication on a frequency near 7,000 kilocycles per second, when ranges of up to 25 miles were obtained, and use by the master bomber of a modified TR.1143 transmitting on about 36 megacycles per second, the remainder of the aircraft receiving his instructions by using S.B.A. receivers. The methods were not entirely satisfactory and in August 1943 use of TR.1196 on the Darky frequency was decided.[2] In the course of raids against Turin on 7/8 August and Milan on 12/13 August good results were obtained, but effective interference was expected on the Darky frequency over Germany. It was therefore decided to use both T.1154 and TR.1196 in the pathfinder aircraft and R.1155 and TR.1196 in the rest of the bomber force in order that the strength of signals and range of reception might be improved and to provide two communication channels. This method became standard practice, but the efficiency of the system was often impaired by too much talking and interruption by main force aircraft and by the lack of clear-cut concise instructions from the master bomber.[3]

The effectiveness of bombing raids was greatly increased by employment of the Master Bomber technique, but it was considered in No. 5 Group, which provided the master bombers for attacks against multiple objectives, that the effectiveness could be doubled by use of V.H.F. R/T.[4] Interference experienced when TR.1196 was used was too great to permit anything like maximum efficiency being attained, and control by W/T was too slow and cumbersome. Unless the master bomber was able to pass his instructions instantly it was possible for the centre of the whole attack to shift appreciably within a minute or so. The ideal solution was installation of V.H.F. R/T equipment in all aircraft of Bomber Command, but it was thought that until that could be brought about its installation in aircraft of No. 5 Group would result in improvement of bombing results since information could be passed accurately and quickly between aircraft of the marking force. Consequently, in April 1944 Headquarters Bomber Command asked for special provision to be made for squadrons of No. 5 Group. In May 1944 it was decided that sufficient TR.1143 installations could be made available for that purpose, but the remainder of the command would have to be equipped with SCR.522. In June 1944 aircraft

[1] A.H.B./IIE/44. V.H.F. R/T had been employed for air-to-air communication during the attacks against the Moehne and Eder dams.

[2] A.H.B./IIH/241/3/838. The Master Bomber technique was developed to provide the bomber force with minute-to-minute information of the progress of a raid, to issue warnings of misplaced markers, to give the position of decoys, and generally to assist the bomber force to attack the correct aiming-point. The master bomber stayed in the immediate vicinity of the target during the whole period of attack, and reserves were briefed to take his place if necessary.

[3] A.H.B./IIH/241/3/838. A memorandum on this subject was sent to all Bomber Command groups on 3 May 1944.

[4] A.H.B./II/70/373.

of No. 5 Group were fitted with TR.1143, and in the following month those of No. 1 Group were fitted with SCR.522, installation of which in all heavy bombers of Bomber Command had been completed by April 1945, when the fitting of TR.1430 in Mosquito bomber aircraft was begun. Despite the large measure of success achieved with V.H.F. R/T, a W/T communication channel was also made available. It provided an insurance against poor R/T communications at low altitudes, enemy jamming, enemy spoofing and failure of V.H.F. R/T equipment.[1] It also provided a means for keeping group headquarters informed of the progress of an attack and thus enabled the A.O.C. to make the best use of his reserve aircraft and to cancel an attack if necessary.

Further Development of Aircraft Communications Equipment

On 3 August 1943 a conference was held at the Air Ministry to discuss aircraft R/T communication requirements. It was decided that it was not possible to meet future V.H.F. R/T requirements of the Royal Air Force with existing equipment and that the development of new equipment was necessary. It was considered that a single equipment to meet the requirements of both R.A.F. and the F.A.A. could not be developed, and it was agreed to produce the G.E.C. installation to meet all R.A.F. requirements other than those of Coastal Command and to develop another equipment to meet the needs of the Fleet Air Arm and Coastal Command. The time factor was important and delay in the development and production of the G.E.C. project in order that frequency modulation might be incorporated in addition to amplitude modulation could not be accepted. The new requirement was to be based fundamentally on amplitude modulation but provision of frequency modulation for air-to-air working, selection of either being made by a switch, was to be considered. The installation was to be the same size as, and interchangeable with, TR.1143 and TR.1196. Six models of an interim version, known as TR.1407, covering about 100 to 130 megacycles per second, were to be ready for Service trials in September 1944. The final version, providing full frequency coverage from 100 to 156 megacycles per second with 622 frequency channels, was to be known as TR.1533.[2]

Six TR.1407 installations were made ready in September 1944 as planned, but Service trials showed that further development was necessary before production could be started, and the sets were returned to the General Electric Company for improvements to be included. By May 1945 renewed Service trials of installations in Wellington, Beaufighter and Lancaster aircraft had been completed by the Signals Flying Unit at Honiley and the Bombing Development Unit at Feltwell. In general it was considered that air-to-ground performance with amplitude modulation was adequate but performance with frequency modulation was unsatisfactory.[3] The principle of frequency selection employed was satisfactory but many improvements were recommended for inclusion in the equipment before production could be started.

Also well under development before the end of the war was a pilot-operated installation, TR.1501/1502, designed to meet the requirements of Coastal

[1] A.H.B./IIE/76A.

[2] Difficulties encountered with the design of fully tropicalised components were one cause of delay in development of TR.1533.

[3] A.H.B./IIE/44.

Command and the Fleet Air Arm. It was planned to provide reliable multi-channel V.H.F. R/T, and two-channel pre-set H.F. R/T and W/T, for air-to-air, air-to-ship, and air-to-ground use. The method of channel selection employed was the same as that used in TR.1407, and the V.H.F. unit, TR.1501, was built on the same lines as that installation, but covered the full frequency band from 100 to 156 megacycles per second with 180 kilocycles per second separation. Progress of development was hindered by difficulties encountered with frequency selections and other technical problems. The H.F. R/T-W/T unit, TR.1502, covered from 2 to 7 megacycles per second. Both sets used a common power supply and were built to standard dimensions and weighed about 55 pounds.

Design had also been completed of equipment A.R.I.5332, projected to replace the existing general purpose aircraft installation, which was intended to be suitable for use in any part of the world. It was built in three main sections comprising V.H.F., H.F. and M.F. units which were rack-mounted and readily removable, somewhat reminiscent of the three-panel system used in army co-operation squadrons shortly after the First World War. The installation consisted of five units, V.H.F. transmitter/receiver (incorporating features of TR.1407), H.F. transmitter, H.F. receiver, M.F. transmitter and M.F. receiver, and was so designed that one or more could be fitted in an aircraft according to requirements. Ability to receive on M.F. whilst transmitting on H.F., and to receive on H.F. whilst transmitting on M.F., was a specification, but simultaneous transmission on H.F. and M.F. was not; simultaneous transmission and reception on V.H.F. and H.F. was to be possible. The V.H.F. transmitter and receiver had a separate power supply. The M.F. and H.F. transmitter units operated from a common power supply, but the M.F. and H.F. receiver units were given a separate supply so that use of the transmitter supply was avoided during prolonged listening-out periods. The frequency range covered was 200 to 1,200 kilocycles per second, 1·5 to 17·5 megacycles per second, and 100 to 156 megacycles per second. An intercommunication system was associated with the installation and, consequently, production of A.1342 was cancelled, although its development, as a replacement for A.1134, had been completed. No aircraft requiring the simultaneous operation of more than eight intercommunication positions were likely to be in production before A.R.I.5332 was available.[1]

During 1944 development was also begun of an automatic radio compass, A.R.I.5428, principally for use in transport aircraft. To a large extent it was developed in parallel with A.R.I.5332, as the H.F. receiver was common to both. The radio compass was to be effective at ranges up to 400 miles from a 300-watt transmitter with accuracy of plus or minus 2 degrees. It was designed to provide measurement and indication of the bearing, relative to aircraft heading, of a selected transmitting station, automatically or by manual operation (when an aural minimum was used), and standby communication reception of both modulated and unmodulated signals, including those from radio ranges.

An airborne voice-recording system was made an operational requirement in the summer of 1944. One reason was a desire to obtain more accurate and detailed information, in correct chronological sequence, of observations made

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[1] A.1342 was a two-stage amplifier which was designed to be stowed in any convenient position and used in conjunction with a control unit installed at the wireless operators station (A.H.B./IIE/44).

and events which occurred during operational bombing sorties. It was considered that much useful information was being lost because of excitement, forgetfulness and fatigue of crew members. Similar facilities were required for recording tactical reconnaissance observations. No existing equipment fulfilled the requirement, which entailed five to six hours recording time, 'press to record' operation, and high-fidelity reproduction. Suitably modified Model 20N magnetic wire recorders were being used by the United States Navy for recording sono-buoy transmissions, and Headquarters Coastal Command considered that Model 20N would meet the urgent requirement of that command for recorders to be used with sono-buoys.[1] Investigation revealed that the Bomber Command requirement could be met with the same equipment until such time as equipment suitable for universal use throughout the R.A.F. could be produced. Requisitioning action was therefore taken to permit installation in about 500 aircraft and maintenance for about 18 months whilst a recorder was developed at the R.A.E.[2] A development contract for recorders and associated play-back units was also placed with the radio industry.

Beechnut

As the effectiveness of fighter and close-support operations became increasingly dependent on the efficiency of aircraft communication, the vulnerability of the V.H.F. R/T system to jamming became more important. It was considered that the enemy might choose the time of an assault on the Continent to attempt to render the system ineffective by jamming, and after the merits of various proposals had been closely studied, the Air Interception Committee decided on 3 September 1943 to adopt a measure known as 'Beechnut' which was recommended by the Director-General of Signals as being the most suitable.[3] Beechnut, a form of impulse signalling, did not interfere with normal two-way R/T working but provided a transmission, proof against jamming, which conveyed information, from ground to air only, in the form of ideographs, and enabled automatic or semi-automatic acknowledgment to be made from air to ground. This was achieved with the aid of additional equipment, both in the aircraft and on the ground, working in conjunction with the V.H.F. R/T equipment.[4]

The ground equipment consisted of a control unit and a sender. The control unit contained a keyboard, manipulated in a similar manner to a typewriter, and incorporated 66 ideograph buttons arranged in six columns of eleven each, a call-sign selector switch, control buttons and signal lamps. The sender, which controlled the V.H.F. R/T transmitter, served two purposes. It stored a message containing the six ideographs (one from each column of buttons) which was set up on the control unit, and sent the message, in the correct sequence and prefaced by the appropriate call-sign, when the 'send' button on the control unit was pressed. Provision was made at the control

[1] *See also* Royal Air Force Signals History, Volume VI: 'Radio in Maritime Warfare'.

[2] A.H.B./IIE/44. About 250 Model 50 play-back units were also ordered.

[3] A.H.B./IIE/28/24(A). Meetings of R.C.M. Board. A.1420, a one-kilowatt amplifier for use with a V.H.F. R/T ground transmitter, was also developed. When used in conjunction with a high-gain aerial system ranges up to 375 miles with aircraft at 30,000 feet could be obtained, and V.H.F. R/T could be operated in spite of considerable jamming.

[4] A.H.B./IIS/110/9/5A. A.E.A.F. File S.14068.

The efficiency of Beechnut depended largely on the length of time for which it could be employed before the enemy found means to neutralise it and on the thoroughness of organisation for ensuring that the right message reached the right aircraft. There were three variables in the aircraft installation which required rigid control in order that the desired results could be achieved; call-sign, scramble combination, and supersonic frequency channel.

Arrangements were made, with most stringent security measures, to provide enough equipment for installation in all aircraft of night-fighter squadrons, in three aircraft of each fighter and fighter/bomber squadron, and in one aircraft of each day-bomber squadron, and for the appropriate ground stations to be suitably modified. The necessary modifications were made to aircraft V.H.F. R/T installations but the Beechnut equipment was held ready for fitting until such time as enemy jamming of V.H.F. R/T made its employment necessary; in the event the emergency did not arise. Neither Beechnut nor the high-power amplifier, A.1420, was required on D-Day or subsequently, since the enemy made no serious attempt to interfere with the V.H.F. R/T system.

TABLE No. 1

OPERATIONAL CHARACTERISTICS—OBOE MARK I STATIONS. December 1943

Station and Number	Position and Aerial Reference Numbers	Height of Aerials above Mean Sea Level Feet	Radio Frequencies			Baillie Beam Positions Azimuth Arc
			Transmit	Transmit	Receive	
TRIMINGHAM I 9121	52° 53′ 36·34″ N. 01° 24′ 11·64″ E.	246	216	228	232	Caistor 078–140 degrees
TRIMINGHAM II 9131	52° 53′ 24·27″ N. 01° 24′ 41·37″ E.	212	228	236	232	
WINTERTON II 9161	52° 42′ 27·472″ N. 01° 42′ 01·508″ E.	56	212	220	236	
HAWKSHILL DOWN I 9132	51° 11′ 27·843″ N. 01° 23′ 53·219″ E.	160	216	228	232	Oldstairs 0–360 degrees
HAWKSHILL DOWN II 9162	51° 11′ 30·081″ N. 01° 23′ 53·398″ E.	131	212	220	236	
SWINGATE 9122	51° 08′ 07·050″ N. 01° 21′ 24·233″ E.	397	228	236	232	
WORTH MATRAVERS I 9142	50° 35′ 42·370″ N. 02° 03′ 07·850″ W.	416	216	228	232	Worth Matravers 070–230 degrees
WORTH MATRAVERS II 9152	50° 35′ 41·496″ N. 02° 03′ 09·436″ W.	412	212	220	236	
SENNEN 9141	50° 03′ 56·690″ N. 05° 40′ 14·053″ W.	304	216	228	232	Constantine 070–230 degrees
TREEN 9151		326	212	220	236	

TABLE No. 2

OPERATIONAL CHARACTERISTICS—OBOE, MARK II (FIXED) STATIONS

December 1943

Station and Number	Position and Aerial Reference Numbers	Height of Aerials above Mean Sea Level Feet	Baillie Beam Positions Azimuth Arc
WINTERTON I 9211	52° 42′ 30·619″ N. 01° 41′ 59·293″ E.	86	Caistor 078–140 degrees
HAWKSHILL DOWN II 9212	51° 11′ 25·913″ N. 01° 23′ 49·370″ E.	170	Oldstairs 0–360 degrees
WINTERTON III 9221	52° 42′ 25·146″ N. 01° 42′ 03·101″ E.	54	Caistor 078–140 degrees
HAWKSHILL DOWN IV 9222	51° 10′ 57·532″ N. 01° 23′ 42·509″ E.	221	Oldstairs 0–360 degrees

TABLE No. 3

OPERATIONAL CHARACTERISTICS—OBOE MARK III STATIONS

January 1944

Station and Number	Position and Aerial Reference Numbers	Height of Aerials above Mean Sea Level Feet	Baillie Beam Positions Azimuth Arc
CLEADON III 9313	54° 58′ 07·363″ N. 01° 22′ 57·579″ W.	275	Cleadon 090–140 degrees
	54° 58′ 07·855″ N. 01° 22′ 56·760″ W.	275	
CLEADON IV 9323	54° 57′ 58·835″ N. 01° 22′ 49·884″ W.	265	
	54° 57′ 59·318″ N. 01° 22′ 49·022″ W.	265	
WINTERTON IV 9311	52° 42′ 19·960″ N. 01° 42′ 05·830″ E.	52	Caistor 078–140 degrees
	52° 42′ 19·547″ N. 01° 42′ 06·684″ E.	52	
WINTERTON V 9321	52° 40′ 59·101″ N. 01° 42′ 59·270″ E.	49	
	52° 40′ 58·644″ N. 01° 42′ 58·431″ E.	49	
HAWKSHILL DOWN V 9312	51° 10′ 55·285″ N. 01° 23′ 41·595″ E.	225	Oldstairs 0–360 degrees
	51° 10′ 55·595″ N. 01° 23′ 41·604″ E.	225	
HAWKSHILL DOWN VI 9322	51° 10′ 52·342″ N. 01° 23′ 35·939″ E.	221	
	51° 10′ 51·683″ N. 01° 23′ 35·644″ E.	221	
TILLY WHIM 9314	50° 35′ 42·035″ N. 01° 57′ 21·718″ W.	282	Worth Matravers 070–230 degrees
	50° 35′ 41·501″ N. 01° 57′ 22·407″ W.	284	

NOTE: 3150–3180 and 3210–3240 megacycles per second.

TABLE No. 4

OPERATIONAL CHARACTERISTICS—OBOE MARK II (MOBILE) STATIONS

April 1944

Station Type and Number	Radio frequencies in megacycles per second	Baillie Beam Positions, Azimuth Arc
TILLY WHIM II (W.M.) 9411	3,150–3,135	Worth Matravers 070–230 degrees
TILLY WHIM III (S.M.) 9412	3,240–3,225	Worth Matravers 070–230 degrees
TILLY WHIM IV (S.M.) 9412	3,195–3,180	Worth Matravers 070–230 degrees
BEACHY HEAD I (S.M.) 9421	3,195–3,180	Oldstairs 0–360 degrees
BEACHY HEAD II (S.M.) 9421	3,240–3,225	Oldstairs 0–360 degrees
BEACHY HEAD III (W.M.) 9411	3,150–3,135	Oldstairs 0–360 degrees
HAWKSHILL DOWN II (S.M.) 9212	3,240–3,225	Oldstairs 0–360 degrees
HAWKSHILL DOWN IV (S.M.) 9222	3,195–3,180	Oldstairs 0–360 degrees

TABLE No. 5

STATISTICS OF OBOE SORTIES

1942–1945

	R.A.F.					U.S.A.A.F.				
	Raids	Total Oboe Sorties	Successful Oboe Sorties	Percentage	Main Force Sorties	Raids	Total Oboe Sorties	Successful Oboe Sorties	Percentage	Remarks
1942										
Dec. ..	13	25	16	60	8					
1943										
Jan. ..	18	35	28	72	623					
Feb. ..	40	55	34	71	945					
March	45	84	57	68	1,883					
April ..	7	50	36	72	1,609					
May ..	7	78	58	74	3,984					
June ..	10	84	55	65	3,949					
July ..	8	64	42	65	2,400					
Aug. ..	9	76	44	63	2,218					
Sept. ..	11	66	43	65	1,223					
Oct. ..	26	150	86	59	783	1	?	—	—	Jamming
Nov. ..	29	210	101	47	731	1	2	—	—	
Dec. ..	29	192	102	51	54	3	3	—	—	
1944										
Jan. ..	57	318	185	58	256	4	6	2	33	
Feb. ..	65	257	147	57	12	—	—	—	—	
March	121	447	267	60	2,141	8	10	6	60	
April ..	72	346	214	62	4,693	4	14	9	64	
May ..	107	559	300	54	6,089	14	36	29	80	
June ..	188	745	519	69	12,218	54	112	65	58	
July ..	140	699	493	71	8,647	72	163	131	80	
Aug. ..	165	720	532	74	7,941	36	73	59	80	
Sept. ..	130	773	486	63	6,720	3	3	2	67	
Oct. ..	114	623	330	53	9,210	16	34	8	23	
Nov. ..	67	546	227	41	7,083	42	157	90	57	
Dec. ..	61	471	222	45	7,480	69	146	52	35	
1945										
Jan. ..	32	223	142	64	2,626	61	118	39	33	
Feb. ..	64	464	252	54	5,895	99	204	95	47	
March	75	551	362	66	9,283	122	471	262	55	
April	95	569	391	69	6,688	17	107	43	40	
May ..	36	152	133	88	2,548	1	4	1	25	

TABLE No. 6

DEPLOYMENT OF TYPE 9000 CONVOYS

1 March 1945

Unit	Site	Convoy	Channel	Cabin
No. 1/9000	Molsheim	9422	12A	15
		9431	13A	14
		9451	11C	9
		9452	11B	12
No. 2/9000	Laroche	9442	13A	6
		9442	11B	7
		9431	11C	13
		9412	12	62
No. 3/9000	Florennes	9432	13A	1
		9432	11B	2
		9452	11C	11
		9421	12	64
No. 4/9000	Commercy	9441	11B	3
		9441	13A	5
		9451	11C	10
		9421	12	63
No. 5/9000	Rips	9411	11B	51
		9411	13A	52
		9412	12	61
		9422	11C	16
No. 6/9000	Tilbourg	9461		17
		9461		18
		9462		19
		9462		20

TABLE No. 7

OBOE ACCURACY DATA

Type of Operation	Height in feet	Period	Average error in yards
Bombing Operations with Oboe Mark I	—	December 1942–February 1943	650
Bombing Operations	—	March and April 1944	600
Bombing Operations	28,000	May 1944	300
Bombing Trials—Oboe Mark I ..	12,000	April 1945	227
Bombing Trials—Oboe Mark II ..	12,000	April 1945	176
Bombing Trials—Oboe Mark II ..	28,000	April 1945	274

TABLE No. 8

STATISTICS OF GEE-H SORTIES

October 1944

Date	Target	Gee-H Sorties		Failures			Missing
		Used Gee-H	Bombed on Gee-H	Technical	Not Gee-H	Unclassified	
14	Duisberg ..	31	6	3	3	19	—
18	Bonn	41	20	7	1	12	1
22	Neuss	26	18	1	—	7	—
23	Essen	18	14	3	—	1	—
26	Leverkusen ..	34	29	3	—	2	—
30	Wesseling ..	34	30	4	—	—	—
31	Bottrop ..	35	31	2	—	2	—
	TOTALS	219	148	23	4	43	1
	Excluding Duisberg TOTALS	188	142	20	1	24	1

Note.—On the Duisberg raid crews were briefed to bomb visually although they were to operate Gee-H. The majority of the 19 unclassified failures used Gee-H for tracking but did not continue with its use because the releasing pulse was weak. Six navigators reported that they could have bombed on Gee-H. If the Duisberg raid is excluded, 142 of 188 aircraft, that is 75·5 per cent, successfully bombed on Gee-H.

TABLE No. 9

DETAILS OF GEE-H RAIDS

October 1944

Target	Time over Target	Height in Feet	Tracking Station and Range	Releasing Station and Range	Angle of Cut	Weather
					Deg.	
Duisberg	0845	18,000	Commercy 191 miles	Florennes 124 miles	032	Layers of cloud, tops 8–14,000 feet.
Bonn	1100	17,000	Florennes 111 miles	Commercy 149 miles	046	Clear, visibility good.
Neuss	1600	17,000	Antwerp 105 miles	La Roche 77 miles	056	Nine to ten-tenths cloud, tops 8–10,000 feet.
Essen	1930	16,500	Antwerp 121 miles	La Roche 99 miles	047	Ten-tenths cloud, tops 10,000 feet.
Leverkusen	1530	16,500	Commercy 165 miles	La Roche 76 miles	025	Ten-tenths cloud, tops 10,000 feet.
Wesseling	1200	16,500	Commercy 152 miles	La Roche 68 miles	032	Ten-tenths cloud, tops 9,000 feet.
Bottrop	1500	16,500	Volkel 55 miles	La Roche 104 miles	064	Ten-tenths cloud, tops 9,000 feet.

TABLE No. 10

STATISTICS OF SHORAN SORTIES
9–18 April 1945

Method of Bomb-aiming	Sorties		Failures							Average percentage of bombs within 600 ft. of target
	Airborne	Effective	Weather	Dust, Haze, Smoke, etc.	Human Errors	Enemy Opposition	Shoran Equipment	Other aircraft equipment	Other causes	
Shoran Number Percentage	443 —	378 85·3	8 1·8	— —	32 7·2	3 0·7	22 5	— —	— —	80·1
Visual Number Percentage	1,097 —	886 80·8	41 3·7	41 3·7	59 5·4	18 1·6	— —	27 2·5	25 2·3	72·1

APPENDIX No. 1

SURVEY OF GERMAN CENTIMETRIC RADAR RESEARCH AND PLANS, FEBRUARY 1944

Extracts from a translation of a lecture given by Dr. Brandt at a meeting presided over by Field Marshal Milch in the *Herman Goering Saal* on 8 February 1944.

. . . The centimetric waves, as compared to those used to date, have certain advantages in that they can be more clearly focused. A fact, which up to now has not been generally known, is that they possess greater reflecting properties against aircraft. *Staatsrat* Esau has always maintained that this was the case and in the meantime it has been in fact recognised. They are also less easy to jam and are obviously less liable to Window interference and have afforded, for the first time, the possibility of producing a ground scanning apparatus, that is, they have brought a television-like picture into the aircraft. The enemy has recognised these facts and has introduced a 'ground scanner' to ensure success in his attacks against our cities and U-boats (H2S and A.S.V.). He has already introduced this equipment on a large scale. The enemy has also clearly recognised that these waves have other important spheres of usefulness and has equipped his south coast with these sets as a defence against our ships; he also uses them in aircraft and we assume that they have also been installed further inland for defence against our aircraft. We are firmly convinced that they are used on his ships against our naval units.

Up to a year ago, we had—with the exception of research and development—done very little work in the centimetric sphere. In the past year we have tried to make up the deficit as far as was possible with the means at our disposal. It was necessary to collect new data and then to copy the British 'ground scanner' (H2S). We then had to determine the reflective properties against aircraft and what diffusive properties over water were obtainable. We are now in a position to state that the necessary data has been collected and that the successful completion of the task is now only a question of the manpower available for its completion. In the study of these problems, over the past few months, we have enjoyed, both in the *Luftwaffe* Technical Control Office (*Technisches Amt*) as well as in all departments of the Navy, the closest, I may say the friendliest, co-operation of all concerned. We have co-operated in tackling each problem that has arisen and thus achieved the clarity which is ours today. . . . The British H2S (*Rotterdam*) cannot, on account of its size, be built into a German aircraft. We have therefore constructed a smaller set, the *Berlin*, details of which will be explained. It can be broken down into five main components: the high-frequency head, the pulse and intermediate frequency parts, the presentation unit and the control unit. The aerial system used on this set will have a performance at least equal to that of the British H2S. The British have scored a success with the H2S. In the early stages they worked with comparatively incomplete equipment. They used equipment which was very much in its early experimental stages and had to overcome all kinds of 'teething troubles' connected with equipment and technique. In the early stages, technicians were sent out on flights because the fundamental significance of the project was fully appreciated. They recognised that radar was the eyes of the fighting units and that these sets were at their best when their wavelengths were nearest to light waves.

We must realise that in the course of introducing the *Berlin* equipment, we shall also have to employ an increasing number of technicians; we are in complete agreement with the *Luftwaffe* Technical Control Office that failure in this respect would be a grave mistake, the result of which would be reluctance on the part of our forces to introduce this equipment, whereas, it is, in fact, our aim to introduce something entirely new. The British have recognised how this equipment can be further improved. One can obtain a clearer picture when used for ground scanning and the diffusive properties at sea, particularly against U-boats, can be improved.

With this object in view they have developed a set that works on the 3-centimetre wave-band of which the angular resolution is three times as great. Unfortunately, we know nothing regarding the diffusive properties over sea but, in view of the rule that range is dependent upon the amplitude (*Aufstellungshoehe*) in wavelengths, we can expect advantageous results.

In the course of our work together over the past year it has become clear to us that our technical research in the field of the shorter waves must be carried on and we discussed this problem with *Staatsrat* Esau some weeks ago. On the same day that the first enemy 3-centimetre set was discovered it was possible to produce a German valve with the same frequency band. It is essential that we should, first of all, copy this set and, secondly, that we equip our *Berlin* set with a 3-centimetre head in order to gain the information already in possession of the British.

The next important question is to what extent the other radar equipment will have to be switched over to these wavelengths. I have already mentioned that the decisive experiments into the reflective properties of aircraft first gave us the incentive to work in other fields on 9 centimetres. Opinions on this matter differed but the opinion of *Staatsrat* Esau that aircraft reflected considerably better than had been thought was accepted. As a result we must now go into the question of the 3-centimetre wavelength for other radar equipment. . . . The normal viewing equipment of our aircraft is the *Lichtenstein SN.2* with which an approach is made. The spotting of the target over the last few hundreds metres is done by the pilot with the naked eye. In addition, in conjunction with the technical control office, fire-control equipment is being developed which will make it possible, as in the case of A/A. control equipment, to fire merely from indicator readings or dots on the cathode-ray tube. This fire-control equipment is being developed on 50 centimetres in two types : one is the *Pauke A*, an excellent type, the other is *Li.C2B*, a less efficient type. We hope that the question as to which of these two techniques is the right one for fire-control equipment will be answered by the end of the month and is dependent on the result of our experiments. It is essential that we should already be thinking about a successor to the *Li.SN 2* as there is a danger that it will be jammed in the near future. For this reason spot frequencies have been introduced, but these can also be jammed. In addition we still have the *Neptune V* which can also be jammed and is susceptible to Window interference.

We must therefore produce some new kind of equipment. We have at our disposal the *Berlin* which can be taken over practically unaltered, merely needing another type of aerial system. There are two possibilities with regard to viewing equipment for the *Berlin* ; firstly an aerial system such as that of the *Li.SN 2*, built into the turret of the aircraft, which does not give an all-round view but only 70 degrees each way, but which gives a complete panoramic picture of the aircraft present within that arc (*Berlin N1*). The other possibility (*Berlin N2*) is important where the turret cannot be used ; it is to use a simple aerial rod coming vertically out of the wave-front (*Wellenfront*), fixed in front of the turret and capable of swivelling horizontally and vertically by mechanical means, thus attaining the same results as those achieved electrically on the *Li.SN 2*. These are in fact routine experiments requiring no new developments. The *Berlin* set can be taken over in its entirety for the *Berlin N1* and for the *Berlin N2* parts from the *Li.SN 2* will probably have to be used.

Now to the question of firing equipment (*Pauke S*). What is required is an apparatus with a parabolic reflector which can be large or small according to the range required, and with a high-frequency head and intermediate-frequency component of the *Berlin* set. The other parts could be taken from the *Pauke A*. Here again, no new development of equipment is necessary, a combination of these two sets being all that is required. There are a number of technical questions concerning this which will have to be investigated.

Both the basic problems created by airborne fire-control and viewing equipment can therefore be solved on the centimetric wave-band. At the same time, we must consider testing the *Berlin* set as a ground scanner on the 3-centimetre wave-band, to discover what the new enemy technique against aircraft can accomplish. It is obvious that by using an aerial array of the same size one obtains a much sharper focus and better angular resolution of the aircraft. Furthermore, if the improvement shown in the reflective properties of aircraft between 50 centimetres and 9 centimetres continues in the same proportion, it might be possible to use smaller aerial arrays. This is important because of the question of using the turret. As soon as the high-frequency head is available, we must, without undertaking any further developments, apply this knowledge to the 3-centimetre wave-band in order to ascertain whether it would also be possible to switch fire-control equipment over to 3 centimetres at a later date. Thus a much smaller reflector would be possible. This will be particularly important in the problem of controlling the movable guns in bombers by radar, for then for the first time we would have reflectors small enough to be fitted into a bomber.

We must remember that the enemy is working with great intensity in the 1-centimetre field. He certainly realises the importance of this frequency and I am firmly convinced that his laboratories are paying a great deal of attention to 1-centimetre research. I even suspect that he is already testing it at his experimental stations. Consequently we in Germany must allocate strong forces to this field of research. The problem here is not that we are unable to solve it, but rather that if we do not assign sufficient manpower to the task, the enemy will, one day, give us a big surprise. . . .

. . . One may question whether this or that particular piece of active radar equipment is really necessary, but the development of passive radar equipment, that is observation sets, is absolutely essential since, if one does not possess them, one is delivered defenceless into the enemy's hands. We have, unfortunately, experienced what it means to be without this equipment for some time. We must therefore produce a ground radar observation set operating between 2·5 and 12 centimetres and we must seriously consider what is needed on this frequency band to avoid finding ourselves in the same situation again. As a foundation, we already have the first-rate *Korfu* set and to back it up the organisation of the *Blaupunkt* works. The set is already adapted for a frequency band of 8·5 to 12 centimetres and the plans for 2·4 to 4 centimetres are almost complete. It is of the utmost necessity that we should fill the gaps which still exist and develop and produce prototypes of other sets. The next most essential step in the field of development is to replace the hand-operated direction-finder on the *Korfu* set with an automatic direction-finder. This field of ground radar observation must be fully covered between 2·5 to 12 centimetres as quickly as possible, as we already know that the enemy is using equipment on this frequency band.

We come now to airborne passive radar equipment. Here we have the *Naxos Z* set for homing on to a target, which enables the enemy to be located and shot down. This equipment has, so far, only operated on the 8 to 12-centimetre wave-band. Should the enemy use the 3-centimetre wave-band on his raids, we do not possess a *Naxos Z* set which can operate on this frequency. We know that such equipment has already been used and it may be assumed that increasing use will be made of it, and we are unable to provide airborne warning equipment in this wave-band. Intensive work has already been started to convert the *Naxos Z* to this frequency and it is hoped that receivers will be available very shortly. However, we have not yet closed the gap between the new field of 3 centimetres and the old one of 8 to 12 centimetres. It is a matter of great urgency that we should produce a rotary direction-finder to cover the whole frequency band of 2·5 to 12 centimetres as a final solution to this problem. This puts us in a very unpleasant position, for without previous planning and without the necessary manpower, we are faced with the necessity of producing an immediate solution to this problem. We cannot expect new technicians for this task and we must therefore take them from other duties and switch them over to this work. Our rate of progress in this work does not depend upon us, but is dictated by the enemy.

. . . There are of course other spheres in which centimetric radar is of particular importance. For instance, its importance for I.F.F. has not yet been fully ascertained. It is recognised that the interrogation and responder waves must be kept separate from the main station wave, so that interference with the latter does not take place. Most of our I.F.F. sets work on a wave-band of 2·4 to 1·9 metres independent of normal radar waves. The disadvantages of these waves is that, on account of their much greater length, focusing is far less accurate than focusing on 50 centimetres or 9 centimetres. One would then to be faced with a situation where the radar would have a comparatively small range and the I.F.F. a very coarse focus. In particular, however, very good radiation can be achieved when locating over the sea because of the centimetric waves, whilst relatively bad radiation is obtained on the associated I.F.F. working on the longer wavelengths. It is therefore necessary to develop an I.F.F. set which operates in the centimetric sphere so as to achieve the desired degree of focusing and radiation.

We now come to a special field which arises mainly through the use of the 'ground scanner' (H2S). There are, scattered about the countryside, a variety of visual signals to mark airfield boundaries, cross-country routes and the like. What we now have to consider is whether these signs can be treated so as to make them visible on a radar screen. For this purpose we would require a transmitter/receiver on the appropriate wave, that is to say, a sort of I.F.F. set which would not be called upon to fulfil the duties of an I.F.F. set. This type of equipment would be grouped under the name *Gluehwuermchen*. One would, from a purely radar point of view, be able to see airfield boundaries and special air-lanes on the ground scanner. By erecting such a set in the middle of an airfield, one would obtain a simple blind-landing aid. One could also equip warships similarly and in the same way indicate the coastline and the entrances to harbours. The *Gluehwuermchen* is not very complicated and would not require any major plans for development. The enemy is sure to adopt these measures as the advantages are obvious and they do away with the present visual method. Furthermore, the *Gluehwuermchen* technique could be used in formation flying, whereby each aircraft would be equipped with a *Gluehwuermchen* and the leader of the flight with a *Berlin* set. The *Gluehwuermchen* could also be used as a transmitter for agents and here fear must be expressed that the enemy is already exploiting this angle although nothing positive is known to this effect. . . . . I would like to come to the camouflage of the countryside. For this purpose large triple reflectors are being erected on the lakes which give a particularly good reflection on airborne radar sets. Up to now these *Triberg* work only on 9 centimetres and their introduction on the 3-centimetre wave is an urgent necessity otherwise there is a danger that our widespread camouflage measures will afford no protection whatsoever against 3-centimetre radar. We must therefore undertake the necessary research in order to acquire the requisite knowledge.

. . . The question of the use of Window and its influence on our own and enemy radar must also be investigated. All these problems are still practically unsolved in the 9 and 3-centimetre field, not to mention the 1-centimetre field. Furthermore, we must give our attention to the question of jammers, although we do not yet know how successful our jamming of enemy radar on these wavelengths is. It has, however, been established that the width covered by a jamming transmitter in cycles per second is not in proportion to the wavelength but has a definite frequency width. For this reason it is necessary to use considerably more jamming transmitters against centimetric radar than against metric radar in order to cover the whole band. We must not fail to give attention to centimetric jamming transmitters, but must experiment with them on all wavelengths so that we can find out how our own radar is likely to react to enemy jamming. This is an extremely large field which must be covered in addition to active and passive radar. The German Post Office is developing high-powered jamming transmitters fitted with klystron valves. In addition, *Siemens* have developed a jamming transmitter equipped with magnetron which, of course, is not so high-powered. . . .

. . . It is worth while considering what else can be achieved by the use of this technique outside the field of pure radar and radar search. The country which, at an early stage, succeeds in fusing this technique and those closely related to it into an intelligent and useful combination will undoubtedly have a great advantage over those countries which fail to plan along these lines. Particular benefit would be gained from allowing experts in these different technical spheres to work in close co-operation, in order to achieve surprising results. We have only considered a few of the possibilities, and we must maintain constant and comprehensive research in order to deal completely with this subject. I wish to stress one aspect in order to illustrate how necessary it is that we should give these closely related spheres our attention: as an example I would like to draw your attention to bomb-release apparatus. The enemy is already using H2S for bomb-aiming instruments; we know that he has already considered automatic altimeters. In the navigational sphere it is important that we should decide whether to use split direction-finding (*Schnittpeilung*) or angle beam direction-finding (*Winkelflimmerpeilung*). We must further consider to what extent the *Berlin* equipment may be used for formation flying, in an emergency without the *Glühwürmchen*, since it is possible to recognise neighbouring aircraft through the 'ground scanner'. It is still questionable whether this formation flying technique offers any special advantages. Further we must consider the possibilities of its combination with the dead reckoner. An important question is that of rapid location; for just as we have the *Naxos Z* set, the enemy will also develop an appropriate homing receiver, so that we shall only be able to switch on our 'ground scanners' for short periods or they will be picked up by the homing receivers. However, we must hope that the enemy has not previously developed rapid location so that our warning and homing traffic will not be unduly hindered. Another question is that of short-wave modulation, especially for ships' radar. Admiral Stummel has pointed out that it is in no way necessary to view the whole horizon from a ship, but usually only that particular section required, and that under no circumstances should the beam be revealed in other directions. Another matter which will have to be thoroughly examined is that of low-level aircraft detection possibilities, that is to say, that we must ascertain how low it is possible to fly with a 'ground scanner' and still perform useful work. In this respect the British H2S is very unsatisfactory since the quickly changing pictures of the ground cannot be clearly reproduced in the afterglow valve. This aspect must be gone into with regard to the *Berlin* set and we feel confident that we shall achieve more satisfactory results in the matter of low-flying aircraft.

The question of balloon barrages and long-distance location by means of the *Glühwürmchen* also requires our attention. We must also consider whether we should develop a receiver/transmitter with greater sensitivity and power for long-range location. We suspect that the enemy is using such means, as the Technical Control Office informs us that, when taking off, the H2S set always points to the rear without the reflector having been turned. We must furthermore turn our attention to the question of D/F equipment for aircraft. It should be possible, by the introduction of a second aerial array which would point upwards, to cover the whole area. The importance of height direction-finding in the panoramic equipment must also be realised. The control of swivel-mounted weapons by aircraft panoramic equipment is not simple. In this sphere the co-operation of all concerned with this technique is essential. The question of a joint aerial array for radar and radar search on aircraft and shipping must also be gone into. Another important question is that of signal mixing on panoramic equipment. And finally an interesting task before us is that of combining the *Berlin* set with a rear-looking warning set, since up to now a special set has been needed for rear warning.

A very wide sphere which we will have to think over very carefully in connection with the centimetric waves is that of remote control and remote steering. We have not yet given serious consideration to this problem. The question requires the close co-operation of the Technical Control Office and it is certain that centimetric equipment will play a major part in the field of remote control technique. I have endeavoured to give you a short survey of the complete field of centimetric radar and I would like to say that all departments concerned with these matters, the Technical Control Office, and the industry have given their unstinting and friendly co-operation. But the manpower with which we are called upon to manage at the moment is much too small. We need considerably more men to do all that has to be done. The speed and the scope with which this technique will be introduced will be decided by the manpower situation and not by technical ability to carry it out. . . .

APPENDIX No. 2

NOTES ON GERMAN H2S

Extracts from Milch Documents (Volume 59, pages 3930 to 3932)

. . . Shortly the *Rotterdam* set (German copy of H2S) will be celebrating its first anniversary. It was on 12 February last year (1943) that the industry received the set from a shot-down aircraft. In ten weeks we had copied the H2S and had it functioning. It was demonstrated early in June. In the meantime a number of these sets had been built and, in addition, we had developed the *Berlin* set which was to serve the same purpose. There is very little difference between the *Berlin* and H2S. The H2S scanner was too large for our aircraft to carry. The scanner was so redesigned, that whilst retaining its electrical efficiency (focusing), it was now possible to install the *Berlin* set even in the *Ju. 88*.

H2S operates in the completely blacked-out cabins of enemy four-engined bombers. It works on an indicator system with afterglow effect and demands the concentration of the human eye for a period of ten minutes. The use of afterglow effect was impossible under German conditions. It was necessary for the operator in a German aircraft to be able to remain in his seat and watch the viewing apparatus with normal light conditions and in a normal aircraft. An indicator instrument without afterglow effect was produced by stepping up the rotation speed of the scanner to 400 per minute, whereas the British scanner revolved at 80 per minute. This was only made possible by the construction of a new scanner. In addition to the scanner and the new indicator method, our main achievement was the reduction in the size of the set. The H2S set had a volume of over 21 cubic feet, whilst the German set, which has the same technical performance, has a volume of under nine cubic feet. The weight of the H2S was 235 kg ; the German set although made entirely of steel in order to avoid using materials in short supply, weighs only 180 kg. When comparing this to other German airborne radar equipment, one must bear in mind that nearly all these are constructed of light metals. Since the same performance was desired, the number of valves could not be reduced ; about 50 valves have been retained, but they are practically all normal radio valves.

The German set is constructed in such a manner that no fitting or bench assembly (*Leerenbau*) is necessary and thus large numbers can be produced without difficulty. We have produced an experimental series of ten sets, five of which have been tested and are ready for use. The prototype, after having had its ground tests, has been installed in an aircraft in the past few days and is now ready for flight tests. Furthermore, an initial series of 100 sets has been planned and production of these will begin in March (1944).

The problems of reproducing the British set in the form of the *Berlin* set taxed the combined efforts of our technicians and industry to the utmost in order to make the complicated H2S set both portable and capable of operating under German requirements. Instead of the 14 component parts, we in Germany have managed with four main parts which, with the exception of one, do not require operating. Instead of the 60 cable leads to connect up the various pieces of equipment, we have 11 multi-plugs. Everything has been done to retain the performance and potentialities of the set whilst adapting it to German requirements. It must be mentioned that the performance of the set is dependent on the personnel being able to extract from this ground scanner its full potentialities. We in the industry fear operators will be disappointed when they receive the first sets. They just have to learn to interpret the pictures obtained. The presentation on the British and German sets is certainly the same, the German one may be slightly better. The exploitation of the military possibilities which these pictures provide is exclusively in the hands of the personnel operating the sets.

APPENDIX No. 8

FLOWER CODE FOR GEE STATIONS, JULY 1942

Code	Meaning
Buttercups and Daisies	General Operations
Deadly Nightshade	Single Target Concentrations
Snowdrops	Mine-laying
Forget-me-not	Sea-rescue
Double Daisy	Combined Operations
Love-in-the-Mist	Blind Bombing
Wallflowers	Unclassified Operations
Red-hot Poker	Nuisance Raids
Lilies of the Valley	Aircraft
Orchids	Gee-Aircraft
Rock plants	Heavy Bombers
Sweet William	Medium Bombers
Pansy	1–50
Carnation	50–100
Begonia	100–200
Chrysanthemum	200–300
Hollyhock	300–400
Sunflower	400–500
Princes Feather	500–1000
Crown Imperial	Over 1000
Lupin	Target Correction—Stenigot
Crocus	Target Correction—Gibbet
Bluebell	Target Correction—West Prawle
Clarkia	Target Correction—Truleigh
Rose	0·01
Lily	0·02
Tulip	0·03
Pink	0·04
Iris	0·05
Poppy	0·06
Stock	0·07
Aster	0·08
Geum	0·09

APPENDIX No. 4

DETAILS OF THE OBOE SYSTEM

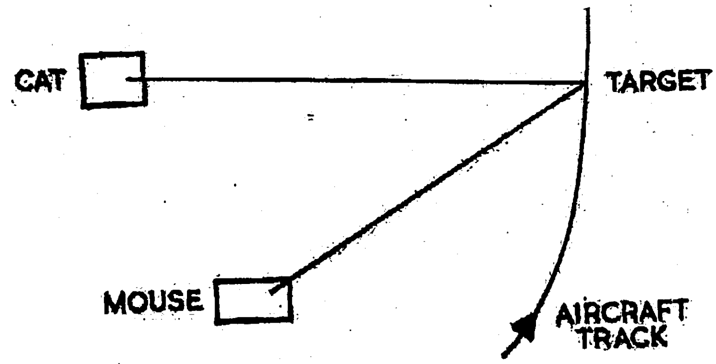
1. The Principle

Oboe was a system of blind bombing whereby an aircraft was controlled by range measurements from two ground stations. Each ground station transmitted pulses on different pulse recurrence frequencies and the aircraft carried a pulse repeater to provide adequate signal strength at the ground station over great distances. The controlled aircraft flew at constant range measured by normal R.D.F. means from one station, the Cat, such that the track took it directly over the target. At another ground station, the Mouse, usually located about 100 miles from the Cat, the aircraft's range and the component of groundspeed along the line joining the Mouse with the target were measured, and from this, in conjunction with a knowledge of the ballistic data of the bomb, the point at which the aircraft must release its bomb was determined and a signal given to the aircraft accordingly.

Signals were transmitted on the same R.F. channel as that used for range measurement

(*a*) to the pilot to assist him to keep on track;

(*b*) to the bomb-aimer to indicate the moment of release.



2. Development of Oboe

Oboe was developed along a number of different lines, the main ones being as follows:—

(*a*) *Frequency*. Two main frequency bands were used:

(i) 1½ metres: 211 to 236 megacycles per second.

(ii) Centimetre: 3,150 to 3,240 megacycles per second.

(*b*) *Modulation*. Two types of modulation were used:

(i) Space modulation of alternate pulses.

(ii) Width modulation of all pulses.

(*c*) *Range*

(i) The ground stations could directly control the bomber up to ranges a little in excess of optical.

(ii) The range of the bomber could be extended by flying a repeater aircraft along a line between each ground station and the target. This repeater aircraft received modulated pulses from the ground station and retransmitted them to the bomber. It also received unmodulated pulses from the bombers and retransmitted them to the ground station. The system called for at least two radio frequencies to be used alternately in successive links of the chain.

(*d*) *Control of Repeater*

(i) by means other than Oboe.

(ii) by splitting the original ground transmission in a *Lorenz* manner.

(e) Development of K System

(i) Normally reception and transmission took place on only one frequency but this was found to be susceptible to interference on the lower frequency band.

(ii) Transmission from ground to bomber could take place on two frequencies simultaneously; this was the K system. The bomber had two receivers, one on each frequency, which fed to a coincidence valve which did not conduct unless the outputs of the two receivers occurred simultaneously. This reduced the interfering effect produced by spurious pulses on a single frequency. The channel bomber-ground station was on single frequency only.

(f) Control of More Than One Aircraft Simultaneously. (This section should be read only after section 4.)

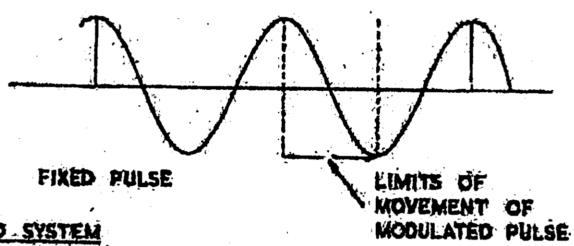
(i) This could be done by erecting further pairs of ground stations, each pair being on a different radio frequency or, as in the K system, on a different pair of frequencies. Thus, with four available frequencies A, B, C and D:

the first pair transmitted on A and B and received on B;
the second pair transmitted on C and D and received on C;
the third pair transmitted on A and D and received on D;
the fourth pair transmitted on A and C and received on A.

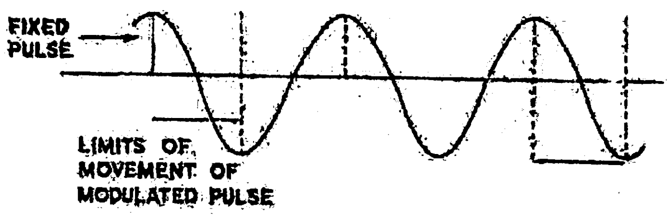
(ii) It was possible to develop the K system in the following way:—

Each fixed pulse was transmitted 133 times per second. The modulated pulse varied in space in the first quarter of the cycle instead of, as in Oboe Mark IA, in the third quarter thus:

NORMAL MARK IA

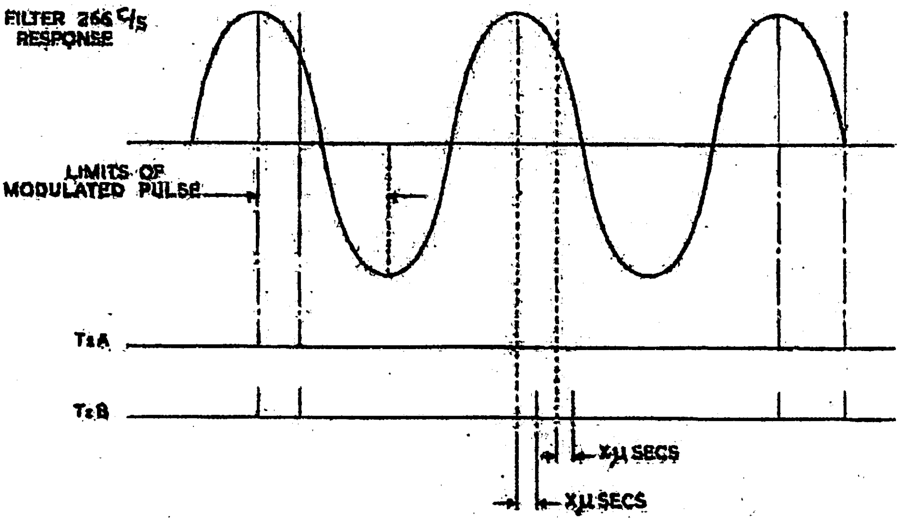


MODIFIED SYSTEM
FOR DUAL CONTROL



These pulses were transmitted on the normal K system, *i.e.* on two radio frequencies simultaneously.

At the half cycle a second fixed pulse was transmitted on the two transmitters, not simultaneously but separated by x microseconds, and the modulated pulse was transmitted on two transmitters separated by x microseconds within the third quarter of the cycle. An aircraft, carrying two receivers, between the output of one of which and the coincidence valve was an x microsecond delay, would receive only the pulses in the second half cycle.



The ground transmitter was therefore being pulsed at 2 by 266 cycles per second (Cat) or 2 by 194 cycles per second (Mouse), but only alternate half cycles were being received by each of the two aircraft under control, *i.e.* one aircraft was fitted with the normal K system to receive, interpret and retransmit the A pulses while the other had a K system with an x microsecond delay in one receiver output to deal with the B pulses.

The ground displays were duplicated, each displaying only alternate half cycles, *i.e.* each display control led one aircraft. Both the long and short time-bases were displayed on one tube but later the layout was redesigned so that each display system could be mounted in one rack instead of three.

(iii) A scheme similar to (ii) above was possible utilising one radio frequency only, but necessitating two ground transmitters H, K. In the first half cycle, transmitter K was fired y microseconds after transmitter H. In the second half cycle K was fired z microseconds after H. The output of the aircraft receiver was split, one going direct to one grid of a coincidence tube, the other through a y or z microsecond delay to another grid of the same coincidence tube. Thus the coincidence tube did not conduct, and therefore did not pass the pulse to the filter and transmitter, unless the pulses which were received were displaced by the time interval of the particular delay in the aircraft.

(iv) Several pairs of ground stations could be used all on the same radio frequency, but each using a different pulse recurrence frequency. This called for a pulse recurrence frequency selector in the aircraft whereby four such pairs of ground stations could operate simultaneously on the non-repeater system. Thus with four radio frequencies, 16 pairs of ground stations and 16 aircraft could be controlled at the same time.

(v) A number of separate displays, each associated with a particular aircraft by reason of a different pulse recurrence frequency as in (iii), could share the same radio frequency equipment, viz. transmitter and receiver. All pulse recurrence frequencies were derived from a common calibrator.

(*g*) It should be noted that apparatus for Marks IA, IK, IB and IIA was largely hand-made, each unit being constructed and set up individually, and therefore unsuitable for production. Marks IIB and III were designed with a view to production.

3. The Apparatus

(*a*) *Ground Station.* Each ground station comprised a pulse transmitter (in Mark IK there were two pulse transmitters firing synchronously on different radio frequencies) and a receiver. The ground ray and aircraft signal were displayed on a time-base on to which calibration pips could be switched at will. A strobe could be positioned along this time-base such that any fifteen miles or less could be taken and displayed on a second and very fast time-base, the speed being such that a 'mile' could be displayed as a length of trace up to 5½ inches long. The target range was defined on this very fast time-base as a blacked-out spot. The ground station also included a modulator which modulated the pulses and conveyed information to the aircrew to enable them:

(i) to keep at constant range from one ground station (Cat)

(ii) to release the bombs at the correct instant according to signals from the other ground station (Mouse).

Each ground station worked on a different recurrence frequency from the other, this frequency being controlled by a crystal-controlled calibrator. The crystal-controlled calibrator oscillating at 93·120 kilocycles per second gave rise to a pip at each oscillation, the time between any two consecutive pips corresponding to one mile when displayed on a time-base. These mile pips were passed through a 'series' of counting stages such that either:

(i) each 700th pip occurring 133 times per second or

(ii) each 960th pip occurring 97 times per second

gave rise to the pulse recurrence frequency controlling:

(i) the transmitter

(ii) the time-base.

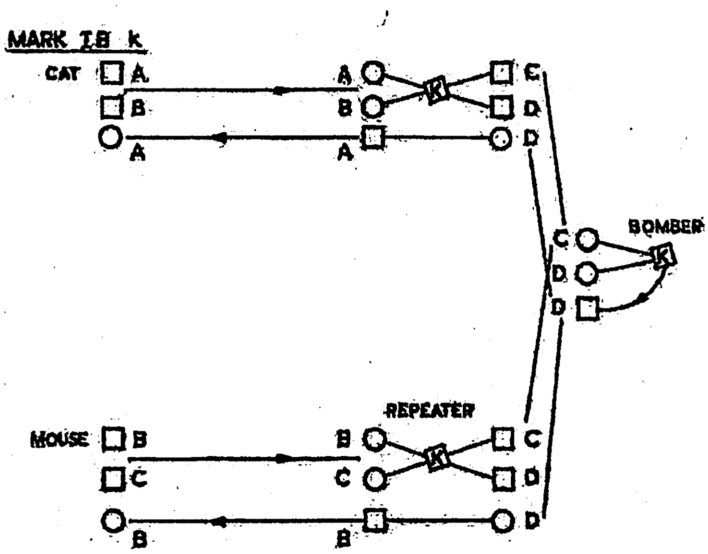
(*b*) *Bomber Aircraft.* Each bomber carried a receiver, the pulse from which triggered a transmitter. The pulses from the receiver or from the trigger unit were fed to a double filter, each portion of which was tuned to the recurrence frequency of one of the ground stations (one to the Cat P.R.F., the other to the Mouse P.R.F.). The outputs of the filters were fed as an aural indication to the pilot and the observer respectively. In Oboe Mark IK, the aircraft carried two receivers which were fed to a coincidence valve and which conducted, passing pulses to the trigger unit and filter, only when pulses were received simultaneously by the two receivers.

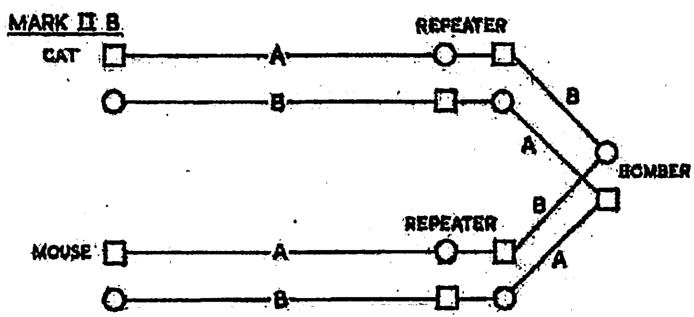
(*c*) *Repeater Aircraft.* Each repeater aircraft carried two transmitter and receiver sets, one set dealing with pulses from ground station to bomber, the other set dealing with pulses from the bomber to the ground station.

In the Mark IK system the set dealing with pulses from ground station to bomber was doubled and comprised two receivers feeding a coincidence valve which fired two transmitters simultaneously. In all cases the receiver of the outgoing set was suppressed when the transmitter of the incoming set was fired.

In Oboe Mark IIB and Mark III the repeater aircraft carried a demodulator to detect the information conveyed by the *Lorenz* split-beam system at the ground station.

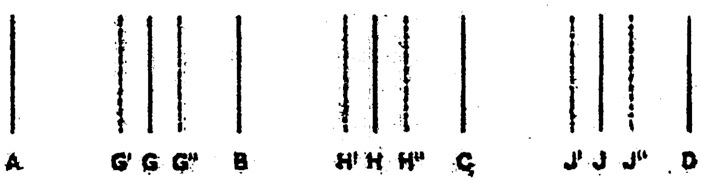
In Oboe Mark IB, however, the repeater aircraft carried a receiver peculiar to the frequency of the Baillie beam and this was quite independent of the Oboe apparatus.





4. The Communication System

(*a*) *Space Modulation.* Alternate pulses were sent out at regular and fixed intervals at a recurrence frequency of 133 cycles per second for a Cat, and 97 cycles per second for a Mouse station. Intermediate pulses were sent out at between $\frac{1}{2}$ and $\frac{3}{4}$, and normally at $\frac{5}{8}$ of the time-interval between the fixed pulses thus:



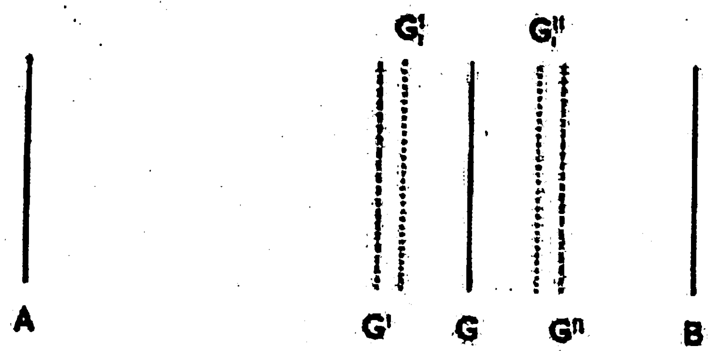
A B C D were fixed pulses

G H J were variably spaced pulses, varying between G' and G'', H' and H'' respectively such that

$$AG = \tfrac{5}{8} AB$$
$$AG' = \tfrac{1}{2} AB$$
$$AG' = \tfrac{3}{4} AB$$

These pulses were received in the aircraft through filters tuned to 266 cycles per second and 194 cycles per second respectively.

When G was in the position G′ it arrived in phase with the oscillation of the filter already excited by A and maintained the 266 cycles per second oscillations, the fourth harmonic of which was passed to the pilot's headphones. When G was in the position G″, however, it arrived completely out of phase with the filter, and the oscillations were immediately damped out and no more was heard in the filter.



If G was at G′ for say 8 pulses and at G″ for 56 pulses then dots would be heard in the phones, but when G was at G′ for 56 pulses and at G″ for 8 then dashes were heard.

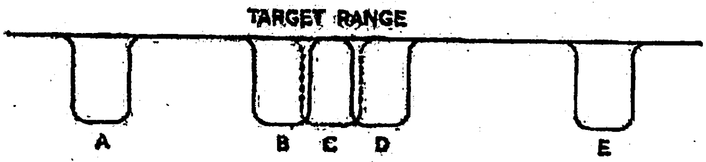
If G was made to vary between G_1' and G_1'' then dots or dashes were heard such that difference in intensities between mark and space was less than when G occupied positions G′ and G″. The percentage modulation under these conditions was defined as $\frac{G_1' \, G_1''}{G' \, G''} \times 100$. When G′ and G″ coincided with position G then a constant tone was heard in the phones of half the maximum dot or dash intensity—this was the equi-signal note which the pilot endeavoured to maintain and which indicated that he was flying at the correct range.

The output of the 266 cycles per second filter worked in this way and was connected to the pilot's phones. The 194 cycles per second filter was connected to the navigator's phones and on this channel pulses G H J etc. always occupied the position G′ H′ J′. Executive signals were sent by cutting the ground transmitter and keying it on and off in a morse manner—' on ' for mark and ' off ' for space.

(b) *Width Modulation.* All pulses were equally spaced in this system and were transmitted at a regular 266 or 194 cycles per second (or at half those rates in the repeater system). The pulses were, however, variable in width between 2 and 4 microseconds. The energy of each pulse was proportional to the product of width and amplitude, but since the amplitude of the pulses was limited at the aircraft, the energy which was fed into the filter was a measure of the width. The filter output was proportional to the energy put in and consequently wide pulses rang the filter more violently than narrower ones and a louder note was produced. In practice the first 2 microseconds of each pulse were cut off so that a series of 2 microseconds pulses did not ring the filter at all, whereas a series of 4 microsecond pulses were arranged to ring the filter to maximum amplitude. Thus a series of pulses consisting of 8 at 2 microseconds, 56 at 4 microseconds, 8 at 2 microseconds etc., gave rise to a filter output maximum depth of dashes. A series comprising 8 at 2·25 microseconds, 56 at 3·75 microseconds, etc., gave rise to a dash output, the depth of modulation being less than the earlier example. When all pulses were of 3 microseconds width, a constant level of output from the filter was produced—the equi-signal which the pilot endeavoured to maintain indicating that he was at the correct range. On the navigator's channel pulses were sent normally at a regular 3 microsecond duration, but when morse or release signals were sent the pulse width was reduced to 2 microseconds for space and increased to 4 microseconds for modulation. In either method of modulation, and on both pilots' and navigators' channels, full depth of modulation could be keyed in a morse manner by operating a morse key.

5. Control of the Aircraft at the Cat Station

Oboe Marks I and IIA. On the very fast time-base (the magnified time-base) was displayed that portion of the time-base on which the aircraft signal appeared when flying at the correct range designed to take it over the target. This range was defined as the centre of a 1 microsecond gap between two associated strobes each 4 microseconds long. The coincidence of the aircraft signal with either or both of these strobes gave an output to the modulator which was a measure of the displacement of the aircraft from its correct track. The aircraft signal displayed



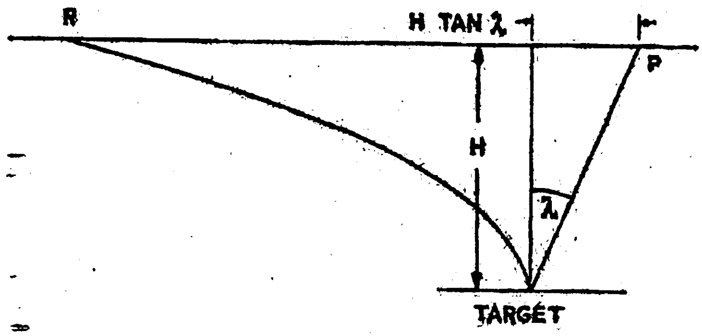
on the time-base was derived from a ringing circuit triggered by the direct signal from the aircraft, in order that a symmetrical pulse was used for action with the double strobe.

When the signal was in position B it was coincident only with one of the strobes, and 100 per cent dot modulation was sent to the aircraft. As the signal moved to the right (*i.e.* the aircraft increased in range) the depth of dot modulation decreased until with the signal at C there was no modulation at all and the pilot heard an equi-signal note. As the signal moved further to the right, the depth of dash modulation increased up to 100 per cent dash when the signal was at D. When the signal was to the left of B or to the right of D, a switch was operated so that the modulation became 100 per cent dot and dash respectively. Thus the aircraft appreciated changes in modulation from 0 to 100 per cent within less than ¼ mile of the track that it should fly.

Oboe Marks IIB and III. On the very fast time-base the target range was displayed as a black-out pip. Also on the time-base was a small 'walking' strobe which when free moved across the trace from left to right with a velocity V. When a signal appeared on the trace, however, the 'walking' strobe could be placed on the leading edge of the signal, on to which it locked; the strobe then moved only with the velocity v of the signal. There existed a certain sponginess between the strobe and the signal proportion to $V \pm v$ and therefore to v. If the voltage proportional to v was integrated with reference to the voltage given by the position of the black-out pip, a voltage proportional to the displacement of the signal from the black-out pip was obtained. This could be positive or negative with reference to the black-out pip and was passed to the modulator which controlled, in accordance with this voltage, the depth of dot or dash modulation to be transmitted.

6. Control of Release of Bombs from Mouse Station

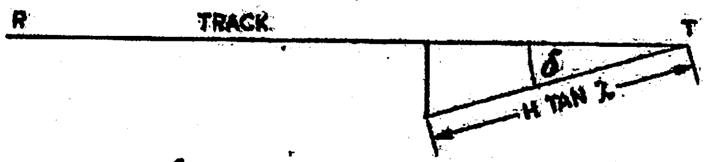
Bomb Ballistics. When a bomb is released from an aircraft its horizontal velocity is initially that of the aircraft, but the effect of air resistance causes the bomb to lag behind the aircraft so that at the moment of impact the aircraft is at P and beyond



the target by a distance H tan λ (called 'the trail distance'). The distance P R (where R is the point of release) is given by G × t where

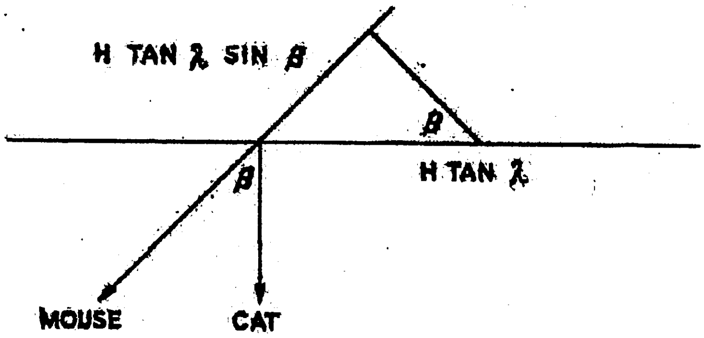
G is the ground speed of the aircraft
t is the time of fall of the bomb.

It should be noted that H tan λ is dependent only upon air speed, height and the type of bomb, all of which factors are pre-arranged, and that the trail distance is always along the reciprocal of the heading of the aircraft. The Mouse station was



δ IS THE ANGLE OF DRIFT

required therefore to give the release signal to the aircraft at a point R which was t seconds flying time away from position T. The point T appeared at the Mouse station to be in excess of the target range by a distance H tan λ sin β, where β was the angle subtended at the target by the two ground stations.



Oboe Marks I and IIa. On the fast time-base were displayed a number of black-out pips generated by a ringing circuit and therefore equally spaced. One of these, L, was placed at a range in excess of the position of the ground ray by the sum of

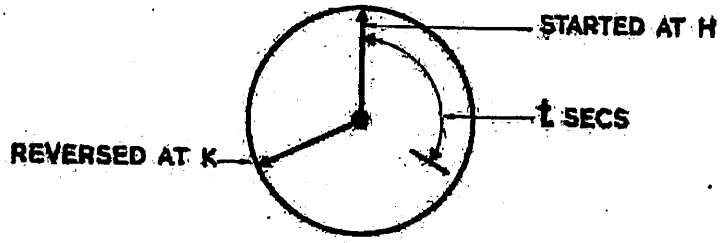
(i) calculated distance from ground station to aircraft at given height vertically above target;

(ii) delay in airborne pulse repeater;

(iii) H tan λ sin β. (This was negative if the aircraft was to approach the target from a range in excess of the target range.)

Two further pips H, K, were selected such that H K = K L, H and K being on that side of L from which the aircraft would approach.

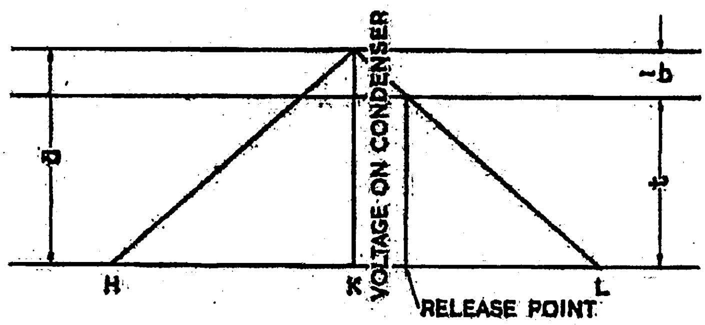
When the aircraft signal passed H, a clock was started and when the signal passed K the clock was reversed. If a constant groundspeed was maintained, the clock should have returned to zero when the signal reached L, but t seconds before reaching L the bomb had to be released, therefore a contact was placed on the clock at t seconds so that when the pointer after reversal touched this contact a



signal was sent automatically. The distance H K had to be such that the aircraft would take at least t seconds to cover it.

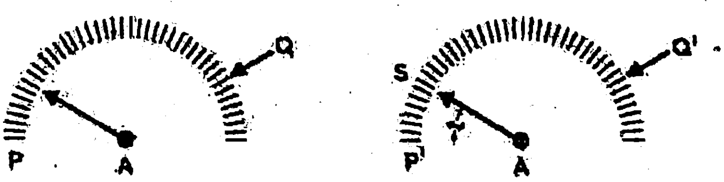
Average Velocity Mouse

The A.V.M. consisted of a large condenser charging through a large resister and discharging through a similar one, the voltage proportion to t being set as a bias to



a valve. The charging was effected through a feed-back time-constant so that it was effectively linear, and the apparatus was set up so that for all values of a, a = b + t and so that t was the required value. A signal was given automatically to the aircraft when the voltage on the condenser fell to a value corresponding to t.

A second type of A.V.M. consisted of two banks of uniselectors each supplied with impulses at a constant rate of 10 per second. At the moment corresponding



to the position of the aircraft signal at H the uniselector A was started and ran from P to say Q, this latter position corresponding to the position of the aircraft signal at K. At this moment uniselector A was stopped and uniselector B was started from a position S where P'S was t seconds (t was the time of bomb-fall) and where P' on B corresponded to P on A. Uniselector B moved until it found the position Q' corresponding to Q on A. When it found Q' a signal was given automatically to the aircraft. This type of A.V.M. was used solely with Mark I and IIF stations.

Instantaneous Velocity Mouse used in Oboe Mark IIM and III

On the fast time-base was displayed a black-out pip which could be set at such a range as to be in excess of the ground ray by the sum of

(*a*) calculated distance from ground station to aircraft at a given height vertically above the target;

(*b*) delay in airborne pulse repeater;

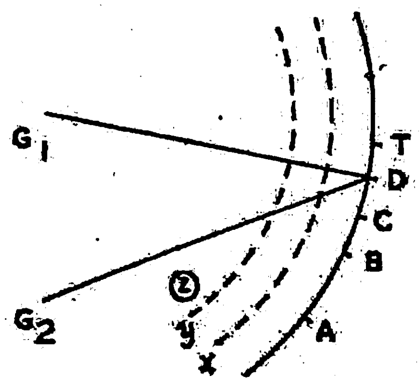
(*c*) $\pm$ H tan λ sin β (as above).

On one side of the trace was a 'walking' strobe (brightness intensified) which, if free to move, travelled across the trace at velocity V. When a signal from the aircraft appeared on the trace, this 'walking' strobe could be placed on the landing edge of the signal, on to which it locked. The strobe then moved only with the velocity v of the signal. There existed a certain sponginess between the strobe and the signal proportional to V $\pm$ v and therefore to v. If the voltage proportional to v was integrated with reference to the voltage given by the position of the target black-out pip, a voltage r proportional to the displacement of the signal from the black-out pip was obtained.

The ratio $\frac{\text{displacement}}{\text{velocity}}$ had the dimensions of time so that an arrangement was made whereby when the ratio of voltage proportional to displacement and velocity respectively was equal to the t.b.f., a signal was sent to the aircraft. The value of velocity thus measured was almost instantaneous and was only dependent on the integrating time-constants.

Alternatively the target black-out pip could be set beyond the ground ray by an amount equal to the sum of only (*a*) and (*b*) above. The trail could then be fed into the Mouse as a time, the time, in fact, for the aircraft to cover the trail distance at an assumed ground-speed. In this case aircraft could be brought in from either side without involving any movement of the black-out pip.

7. The Operation



Each aircraft navigated itself to within an area Z with its Oboe receiver switched on but its transmitter off. The first aircraft of a series switched its transmitter on at a pre-arranged time, but subsequent aircraft switched on transmitters only in response to a call-sign associated with each particular aircraft. The aircraft then flew in a direction approximately at right angles to A T and morse signals were sent to the aircraft as it passed through arcs Y and X at 10 to 5 miles range arc respectively. The aircraft ultimately turned on to the arc at A T and signals were given at A, B, C and D corresponding to pre-arranged distances or times from the target. The distances were such that an aircraft flew from Z to T in less than 10 minutes.

Multi-Channel Control

The limitation of one aircraft over the target every 10 minutes was too severe for target marking when each marker lasted only for 6 minutes and when one faulty aircraft resulted in a gap of 14 minutes. Alternative channels, as discussed in 2 (*f*), were provided, working independently so that with n channels one aircraft could be brought in every $\frac{10}{n}$ minutes on the average.

Essential Data for Operations

(*a*) *Geographical distance.* The arc distance between each ground station and the target were provided by the Air Warfare Analysis Section (A.W.A.S.) together with a correction to be applied for the height of an aircraft vertically above the target.

(*b*) *Bomb ballistics.* The time of bomb-fall and the trail distance of the bomb to be used were supplied in tables provided by A.W.A.S. together with the height of the target above mean sea level.

(*c*) *Bomb load.* Data regarding the type of bomb, number of bombs in the stick, and spacing of bombs within the stick, were furnished by the squadron operating.

(*d*) *Meteorological information.* In order that the apparatus could be set up for greatest efficiency according to the most probable conditions prevailing, the latest available meteorological information was utilised.

Corrections

A correction was applied to both Cat and Mouse ranges because of the fact that the aircraft was travelling along the arc of a circle whereas the bomb was thrown out tangentially. A correction was also applied to both Cat and Mouse ranges to compensate for the cross-trail effect due to components of cross-wind, and, when a stick of bombs was used, a correction was applied to the time of the bomb-fall such that the middle of the stick would hit the target.

APPENDIX No. 5

NOTES ON OPERATIONAL USE OF REPEATER AIRCRAFT WITH OBOE, 31 MARCH 1943

1. Object of Repeater

At present the use of Oboe is limited to attacks on targets within some 270 miles of the ground stations with the bomber at about 28,000 feet. Owing to the straight path along which the signals travel, tangential to the surface of the earth, the range is limited by the height at which the bomber can operate as well as by the height of the ground station. With both the ground station and bomber at their maximum practicable altitudes nothing further can be done to increase the range on any given radio frequency, without introducing an intermediate stage between the ground station and the bomber to relay the signal. This relay system is being introduced by carrying suitable radio relay equipment in a Mosquito aircraft which will require to fly between the ground station and the bomber aircraft.

2. Technical Considerations

This proposed repeater has not yet been flown, but there is every reason to hope, from the radio point of view, that the project is technically practicable. To ensure accuracy in the range measurements and to conform to the propagation path of the signal, the repeater aircraft will be restricted in space to fly to and fro on a certain fixed track between two points. The position of this beat is determined mainly by three variable factors :—

(i) Radio frequency of system

(ii) Heights of repeater and bomber aircraft respectively.

(iii) Distance to target.

For the purpose of this paper, the third factor, distance to target, is assumed to be the maximum possible range of the system, and, therefore, figures for the first two factors only will be given.

The length of the repeater's beat should be sufficient to ensure that it is at the beginning of one of its runs as the bomber commences its own approach to the point of release. The timing must be precise to avoid any possibility of the repeater reaching either of its turning points while the bomber is running up to the target. It cannot effectively relay a signal while turning. If it is intended to continue the present Oboe policy, and aim at an evenly spaced series of bomber runs, 15 minutes spacing would seem practicable at the ranges considered ; bearing in mind the fact that the bomber will be out of range of all precise aids, such as Gee or Baillie Beams, which it has at present, and which facilitate the timing to ensure even spacing. Thus 15 minutes has provisionally been selected for the length of beat of the repeater aircraft between its turning points, or 60 miles at 240 m.p.h. It must also remain at a constant height for the whole period of its runs while an operation is in progress.

The repeater must not approach the ground station closer than 100 miles, and its extreme outward limit is governed by the point at which signals fade. This varies with its height and the radio frequency used. Three possibilities are considered :—

(i) Wavelength 1½ metres, repeater and bomber aircraft at 28,000 feet.

(ii) Wavelength 1½ metres, repeater and bomber aircraft at 25,000 feet.

(iii) Wavelength 10 centimetres, repeater and bomber aircraft at 35,000 feet.

(If Mosquitos with Merlin 61 engines can be provided, a height of 35,000 feet should be practicable, and it is hoped that these will be available at any rate by the time the 10-centimetre Oboe project is developed.)

In the case of (i) above, the maximum certain range between the ground station and repeater aircraft is 250 miles, and between the repeater and bomber aircraft is 400 miles. Thus, allowing for the repeater's beat of 60 miles, we get a total range of 590 miles. In the cases of (ii) and (iii) the total ranges are 620 and 570 miles respectively. Figures 1, 2 and 3 attached illustrate graphically these three cases. It must be emphasised that these figures of range are theoretical, but they have been arrived at after careful investigation of the propagation theory, and any error will probably be an under-estimation.

3. Practical Considerations

Examination of the arrangements of height and wavelength shown in the attached figures indicates that it will be necessary for the repeater to maintain a constant track and height, and carry out its turn at each end of the beat at the correct place, since the range computations for any given target will have to assume a fixed beat. If Berlin is the target, the repeater working with the station at Dover would have to maintain its beat roughly over the Ruhr, and it is a matter for Air Staff decision as to the practicability of this at 28,000 feet. No doubt at 35,000 feet the problem will present a different aspect. Although it has been said that the repeater is restricted to this constant track and height, the following figures may be helpful in planning tactical details. If the repeater aircraft is displaced by as much as 4 miles to one side or the other of its track, and taking into consideration also the additional error due to the possibility of its being at one or other end of its run, the resulting error in range measurement at the target will only amount to between plus 75 yards and minus 45 yards. If the repeater varies its height by 1,000 feet about its mean height of 28,000 feet this will produce an error at the target of plus or minus 25 yards. These figures are again only approximate but serve to indicate the magnitude of errors likely to arise as the result of inaccuracy in navigation on the part of the repeater aircraft.

The aim has been to convey to those concerned with the planning of operations in which the Oboe system will be used, essential facts regarding the use of a repeater aircraft. It is clear that the repeater will possess considerably greater freedom of movement about its assumed track than has hitherto been supposed, but the major problem will be the accurate navigation of the bombers, out of range of Gee or Baillie Beams, to ensure their arrival, at the correct point for running in to the target, every 15 minutes, to synchronise with the repeater's beat.

Regarding the repeater itself two important points emerge. First, because a considerable deviation from its mean track or height introduces so small an error, it will be free to take violent evasive action, provided its turns to port or starboard do not exceed some 20 degrees from the mean track. This turn limitation is necessary because of the aerial arrangement—which is directional. Secondly, for the same reason, navigation of the repeater aircraft could well be undertaken accurately with Gee, which is standard in the Mosquito. At no place, up to the maximum range of the repeater from the ground stations, is Gee less accurate than plus or minus 4 miles, and over most of the area is far more accurate, with possible errors of less than 2 miles.

FIGURE 1

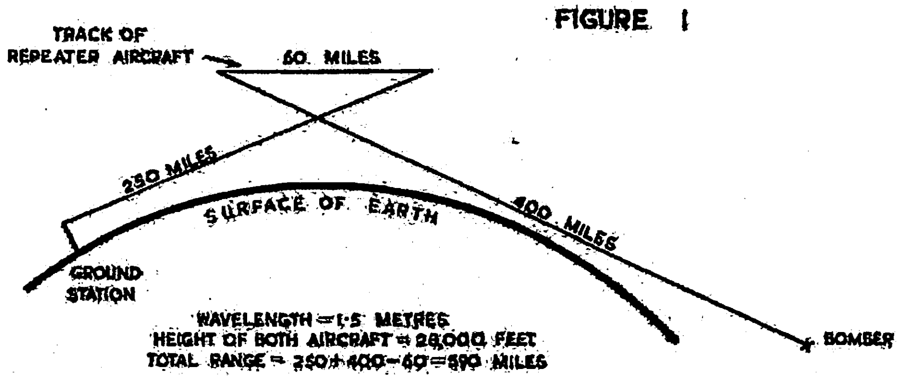


FIGURE 2

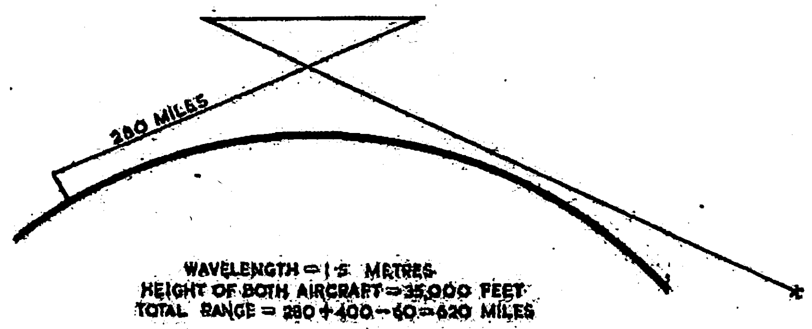
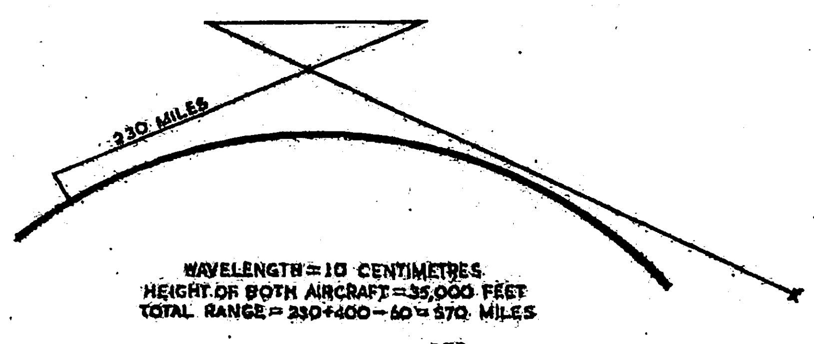


FIGURE 3



APPENDIX No. 6

GERMAN ATTEMPTS TO JAM OBOE

Extracts from Translations of German Documents

1. The 'Holzhammer' Method

After the middle of 1943, German Observation Posts in the Ruhr had recognised the employment of Oboe procedure in air attacks over that area. From August 1943 onwards, 500-watt jammers (continuous dash performance) were set up in the Ruhr and on each English penetration were switched on to the 210–240 megacycles per second band. In January 1944 additional jammers of a similar type, with aerials set eastwards, were erected on the left-hand bank of the Rhine, and by April 1944 the number of jammers set up to protect the Ruhr had risen to 80. At the same time, apparatus for fixing the frequency of the airborne Oboe receiver began to be employed so that each time the greatest number of jammers would be tuned in to this frequency, thus increasing their effectiveness. The Krefeld area was not covered with jammers until April 1944, so that the series of Oboe attacks against the Krefeld *Edel* steel works, which lasted from January to the end of March, were for the most part highly successful. By means of the *Holzhammer* method, jamming was carried out in the 200–250 megacycles per second wave-band until the end of 1944, with constant improvements in apparatus and organisation. During a heavy attack against a *Hydrier* works near Recklinghausen on 15 June 1944, all the Oboe pathfinders seem to have been jammed with great success. Apart from this, for a time an attempt was made to jam the receiver frequencies of the Oboe ground stations in England, from Calais.

On the evening of 21 March 1944, at 1815 hours, a short time before the Oboe flights started, the following morse signal was sent out in German from the English Oboe ground stations by keying the Oboe pulse signal '. . . Hallo, you are a *schweinehund*. . . .' This was received by Calais and accepted as confirmation on the German side of the effectiveness of jamming.

2. The Ball

By this method all impulses radiated from airborne Oboe transmitters and received by the jamming stations were adjusted, synchronised with the Oboe ground receiver frequencies, and re-radiated. A test of this method was successfully carried out on 8 July 1944 during an Oboe flight to a target on the Rhine between Duisburg and Cologne. After several tests in the Arnhem area during August and September, approximately 30 *Ball* jamming equipments were by degrees set up in the Erfurt and Bremen areas and between Utrecht and Mainz, from the middle of October 1944 to March 1945. Although during the setting up of Oboe ground stations in France and Belgium, very few Oboe flights were carried out and the use of *Ball* jammers rendered necessary quite a few tests, the number of successfully-jammed Oboe flights in the northern *Reich* rose from the middle of December 1944. As examples of the jamming results established, the following two days should be mentioned:—

(*a*) On 11 November 1944, four Oboe aircraft flew to Gotha. All were jammed by *Ball* jammers in the neighbourhood of Geldern and no bombs found their mark in the town area. Some were 30 kilometres away and the course of the aircraft was for the latter part very uncertain. During several previous Oboe attacks and one attack some days later against the same target, jammers were not switched on this direction and practically all bombs found their mark.

(*b*) On 17 December 1944, six Oboe aircraft flew to Salzgitter. Five of them were completely and one partly jammed by *Ball* jammers in the Geldern and Hamelin areas. No bombs hit the mark and three bomb-loads were 5–20 kilometres wide of the mark. The remainder could not be found. The headings of the aircraft were very erratic and half of them far wide of the *flak* zone. During all previous Oboe attacks until 3 December, no jammers were set up for the protection of the *Salzgitter* works and nearly all bombs found their mark in the works area. Only one aircraft could be partly jammed from Geldern on 3 December.

The increase in Oboe flights during the first quarter of 1945 (the increase in flights from February to March was about 100 per cent) and other simultaneous air attacks rendered more difficult the establishment of the successful jamming of single penetrations. Of Oboe flights to Bremen 50 per cent were jammed and of those to Wurzburg 25 per cent.

APPENDIX No. 7

JAMMING OF GEE-H, DECEMBER 1944

Extracts from Translations of German Documents

1. It is necessary to render the enemy Gee-H systems so ineffective that it would make target pin-pointing and navigation an impossibility, at least over all home territory, and even over enemy territory.

2. As long as no better plans are submitted, the following is proposed :—

(*a*) Through the use of higher pulse production jamming transmitters the Gee-H ground receivers are to be made to respond at such a high frequency that the Gee-H transmitter must either fail through overloading or merely transmit a mass of jammed signals in which none of the answering pulses from the enemy aircraft is easily recognisable. The transmitters must be tunable to frequencies on which the Gee-H ground transmitter can work. In order to increase the degree of reliability of Gee-H ground receivers responding, in spite of the jamming transmitters being out of optical range of the Gee-H ground stations, the beam can be concentrated and directed against the Gee-H ground receivers.

(*b*) Through one or several monitoring stations

(i) A continuous check must be kept on the effectiveness of every single jamming station.

(ii) Frequency-modulation on the part of the enemy must be confirmed as soon as possible.

By means of this proposed jamming system all navigation by Gee-H over home territory and even over enemy territory (for example, an approach to front-line targets) would be made impossible. A further advantage is that only a comparatively weak jamming signal strength is required on the enemy ground receivers, as it only needs to match that of the weak aircraft transmitter.

3. The jamming or deception of aircraft Gee-H receivers, in a similar manner to the jamming or deception of Gee, demands transmitters in western Germany with an extraordinarily high maximum and average output. Otherwise, because of the characteristics of Gee-H, jamming does not seem to be 100 per cent effective. Nevertheless, an investigation of the following questions is requested :—

(*a*) Whether high-powered jamming transmitters (*Feuerstein* or *Feuerzange*) could be converted to a jamming or deception modulation against Gee-H in order to accomplish effective jamming as outlined in paragraph 2, and whether they hold any promise of success if used in adequate numbers in the form in question.

(*b*) Whether a more effective and quicker method of jamming than that proposed in paragraph 2 is possible on a comparable scale.

4. The necessity for ground and aircraft monitoring equipment, already demanded in order to make possible up-to-date identification of enemy aircraft and ground frequencies, is once more emphasised.

APPENDIX No. 8

MEMORANDUM OF GERMAN CONFERENCE ON JAMMING TRANSMITTERS, 9 JANUARY 1945

Extracts from Translations of German Documents

Present :	Minister Speer	Chairman
	Dr. Heine Dr. Lubeck	Industrial Advisers to Goering
	President Kehre President Gerwig *Oberpostrat* Dr. Scholz	German Post Office
	Dr. Luschen	Radar Committee
	Dr. Gauzenmuller	Secretary of State for Railways
	General Martini General Burckhardt Colonel Knemeyer Major Harmening Major Buchmann Captain Hurner	

1. The subject of the conference was stated by Minister Speer to be :—

How and against what are jamming transmitters to be employed ?
What further measures can be taken to improve the jamming organisation ?

2. The effectiveness of various navigation methods, and the importance of jamming them, was discussed. For pin-pointing a target the enemy prefers to use Oboe. Gee-H is also frequently used. Speer considers it to be of vital importance that these two methods should be jammed. On the other hand Gee-H is much less accurate, even in the front line, for, according to Intelligence reports, it is no longer to be used for bombing main German front-line positions, because of the danger to their own positions. The 'ground scanning' type of radar has the advantage of having a constant proportionately good degree of accuracy for the whole of Germany and is used in bombing raids taking place now.

The immediate jamming of all radar navigation methods is acknowledged to be an absolute necessity. Moreover, jamming of the centimetric wave-band, and therefore of 'ground scanning' equipment, is considered to be of the utmost urgency for, as the Director-General of Signals pointed out, there is a steady changeover by the enemy of frequencies to the centimetric wave-band, and the operational use of centimetric Gee-H is to be expected in the near future. The Director General of Signals states further that the radio interception service is now, to a large extent, able to predict, from radio traffic, the time and place of Oboe-controlled bombing raids up to 20 minutes beforehand. Moreover, Speer reports that a higher percentage of hits have been confirmed on Oboe-controlled raids than on raids using equipment of the 'ground reflection' type, for example, Gee-H. The Signals Staff, General Headquarters, credits this however to the higher standard of training of aircrews of Oboe squadrons.

3. To increase the protection of industrial plants and road and rail junctions in the west, an increase in the use of jamming, or a speed-up in the delivery of transmitters, is essential. Industrial areas in the Ruhr must take top priority in places to be protected by jamming. Following that comes the area stretching southwards as far as Frankfurt and then areas lying to the east. The delay in construction and use of high-powered transmitters is blamed by the Technical Air Supplies department on transport difficulties.

In answer to the Director General of Signals' query as to whether the modulation of high-powered jamming transmitters was now free of faults, Colonel Knemeyer replied that the defects discovered to date could be overcome immediately. Major Harmening stated that the high-powered transmitters would be ready for operations in sufficient numbers in three months' time and at full operational strength in five months. The importance of delivering two completed anti-Oboe jamming transmitters each week, as Goering had demanded, is stressed. The Director General of Signals pointed out that there might be a hold-up in the output of anti-Oboe equipment due to all available stocks of *Kumark* rotating cabins being used up. The Technical Air Supplies department states that a suitable substitute is now available.

The Post Office representatives then made a statement on jamming transmitters used against the ground scanning type of radar (H2S). They expect three transmitters to be produced in the very near future for use in close co-operation with the industrial plants to be protected. *Oberpostrat* Dr. Scholz presented a method of stepping up the jamming power in the protected area by using a large number of extremely low-power centimetric *Ball* jamming transmitters. To cover the Laubfrosch zone, he estimates that four of these transmitters should be installed at one point. This increase in effectiveness would give a better protection of industrial plants, extending right up to the maximum effective range. General Burckhardt objected that such stepping-up would, after a time, provide the enemy with navigational assistance, as had centres of A/A concentration. Dr Scholz denied that this was possible. Dr. Luschen stated that, in order to step up the output of jamming transmitters, technicians were needed.

The Director General of Signals felt that the definite and constant lag of German jamming measures behind the new developments of the enemy would have a lasting and detrimental effect on the German war effort in the field of radio engineering. In order to remove this serious disadvantage the Director General of Signals demands that all possible means are devoted to the development and manufacture, in sufficient numbers, of jamming transmitters with wavelengths down to one-tenth of a millimetre.

4. The following measures are to be introduced to improve the jamming organisation :—

(*a*) Transport difficulties are to be overcome through the personal intervention of the Secretary of State for Railways.

(*b*) Labour difficulties are to be overcome through the mediation of President Kehrl.

(*c*) The time taken to build jamming stations is to be shortened through the co-operation of the Speer organisation with assistance from the industrial plants to be protected.

(*d*) A commission on jamming is to be set up, under Dr. Heine, to deal with any further difficulties and to discuss in detail the measures proposed at (*a*), (*b*) and (*c*). There is a strong possibility that fresh difficulties in production may arise, as a total of 240,000 skilled workers is being withdrawn from the industry at the rate of 80,000 every three months.

APPENDIX No. 9

GERMAN NOTES ON USE OF AIRBORNE JAMMING TRANSMITTERS, JANUARY 1945

Extracts from Translations of German Documents

1. Use of Airborne Jamming Transmitters by the Enemy

With reference to the use of airborne jamming by the enemy the following facts must be borne in mind. It is known that the enemy uses a large number of jamming aircraft against German high-frequency signal transmissions when large-scale flights are made over Germany. This fact leads one to consider whether the same method could not be used on our own operations. There is, however, a fundamental difference between our own and enemy airborne jamming. The enemy must carry airborne jamming transmitters when flying over *Reich* territory, since no effective jamming system from ground stations against German radar devices is available to him. Jamming from our own aircraft would mostly take place over the *Reich*, an area in which an extensive jamming system from ground stations exists, and which has far more effective means at its disposal. It is evident, therefore, that airborne jamming is only necessary when no ground jamming system is available, as in flights over front-line territory or over enemy territory.

2. Possibility of the Enemy Homing to Airborne Jamming Transmitters

By using suitable homing receivers the position of all airborne jamming transmitters can be plotted. This greatly increases the danger of the jamming aircraft being shot down. This can be reduced, however, by installing the transmitter in very fast aircraft, the *Arado 234* for instance. Due to the limited space of such aircraft, however, they can be fitted only with jamming transmitters of limited output. The danger of jamming aircraft being shot down could be reduced still further if the transmitters are used for short periods only. In order to produce sufficiently effective jamming this measure necessitates employment of a much larger number of jamming aircraft.

3. Airborne Jamming against Enemy R/T

The successful employment of airborne jamming against enemy R/T can be achieved only if jamming transmitters can be installed in fighters. It should be used only in daylight hours. It is also essential that operation of jamming transmitters is simple enough to enable it to be carried out by the pilot of a single-seater aircraft. The jamming transmitter must be capable of jamming on all frequencies used by the enemy.

4. Airborne Jamming against Gee

The following technical possibilities exist in the use of airborne jamming against the Gee system :—

(*a*) The *Wolke* jamming transmitter, to be ready in three months' time, has, owing to its limited range, no advantage over the established ground stations.

(*b*) The *Kettenhund* transmitter is even less effective because of its low power.

(*c*) The *Heinrich* jamming transmitter, already in operation as a ground jamming station, possesses a much greater jamming range because of its greater power. It would, however, be difficult to install in aircraft because of its weight and need of a large power supply.

It is technically impossible to install the large jamming transmitters, which, because of their high power, would have an effective jamming range, in aircraft. The limiting jamming range of an airborne jamming transmitter demands the employment of a number of jamming aircraft in order to jam effectively an enemy bomber formation, even if it is only to achieve an effect approximating to that of the ground jamming station.

5. Airborne Jamming against Gee-H

According to the latest information on Gee-H one must differentiate between metric Gee-H and centimetric Gee-H (micro-H).

(*a*) The same considerations are applicable to the airborne jamming of metric Gee-H as to its use against Gee. As with Gee, jamming or deception of the aircraft Gee-H receiver requires the construction in western Germany of jamming transmitters with a very high maximum and average output. However, because of the characteristics of Gee-H, this method does not appear to be completely effective. It could only be made effective, and even then its success is doubtful, if a jamming or deception modulator were fitted. This type of equipment could not, however, be installed in aircraft. The answering of the ground transmitters with a pulse recurrence frequency so high that it would cause the transmitters to break down appears to be the most effective method of jamming at present.

(*b*) Jamming transmitters suitable for use against centimetric Gee-H have not yet been built and production of such transmitters in the near future seems unlikely.

6. Airborne Jamming against Loran

The considerations for the airborne jamming of Loran are similar to those for the jamming of Gee.

7. Airborne Jamming against Oboe

(*a*) Against metric Oboe only jamming transmitters which are fitted with search devices would be suitable for use in aircraft. Because of the short time taken to make the approach to a target—it lasts only eight minutes, in which time the frequency must be determined, transmitted from a ground station to the jamming aircraft, and the aircraft transmitter tuned accurately to this frequency—it appears that the use of airborne jamming does not hold much promise of success. Because of its comparatively short jamming range, the jamming aircraft would have to orbit the actual area to be protected in order to be effective. If the enemy should attack a target other than that protected by the jamming aircraft it would be impossible to switch the latter to the new target because of the high speed of the attacking aircraft (Mosquito).

(*b*) Since suitable jamming apparatus for use against centimetric Oboe is not available and is not to be expected in the near future, the demand for it must remain of secondary importance in favour of the speeding up of the construction of ground jamming stations (the *Ball* system) already in hand. The use in aircraft of the *Ball* jamming system is technically impossible.

8. Airborne Jamming against Enemy Radar Ground Stations

Aircraft jamming enemy radar ground stations can use only low-power transmitters (*Wolke* or *Kettenhund*) the small power units of which can be housed in the aircraft itself. Because of their short jamming range the jamming aircraft would have to be used in front-line areas and even over enemy territory itself if they are to prevent the detection of our own aircraft on flights over the enemy *hinterland.*

9. Airborne Jamming against Metric-wave Searching Sets

The use of airborne jamming transmitters against enemy airborne search equipment on the metric wave-band (night fighter search equipment *Luchs*) is no longer worth while because of a great reduction in the use of such equipment. Jamming transmitters have not yet been produced for use on the centimetric wave-band (night fighter search equipment *Frankfurt* and *Grille*).

10. Airborne Jamming against Centimetric-wave Ground Scanning Equipment

An essential for the effective jamming of enemy ground scanning equipment (H2S) operating on the centimetric wave-band is a highly directional jamming beam. This is a possibility where suitable jamming transmitters are established on the ground. It is absolutely impossible, however, to transmit a highly directional beam from an aircraft.

11. Conclusions

To sum up, it must be stated that, apart from jamming enemy R/T traffic, consent cannot be given for the use of airborne jamming transmitters over the *Reich*, both on tactical and technical grounds. Moreover, consent can only be given for the use of airborne jamming equipment against enemy R/T on the condition that the jamming transmitter is fitted only in fast aircraft, capable of higher speeds than the enemy fighter cover. On flights over enemy territory or in front-line areas airborne jamming is only possible when very fast and suitable aircraft are used. At present suitable jamming transmitters are not available.

APPENDIX No. 10

NOTES ON WIRELESS DIRECTION FINDING

From the earliest days of wireless telegraphy, the directional properties of aerials were known and the practical application of these properties soon became an important factor in marine and air navigation. In the absence of radio communication, a ship or aircraft could determine or keep track of its position by dead-reckoning, map reading, or astronomical observation. But in aircraft, D.R. navigation might easily become inaccurate owing to unknown or changing winds; map reading was only possible in clear weather when flying below cloud; and astro-navigation was also dependent upon good weather conditions, as well as being really applicable only to long flights. Similar hazards were always present in marine navigation, but their danger became many times greater with the infinitely greater speed and shorter endurance of aircraft.

In ships, then, direction-finding by wireless was little more than a check on the older methods of navigation—valuable and universally employed, but not perhaps imperative. With aircraft it became of vital importance, and the organisation of civil and military flying between the wars became dependent upon the existence of an efficient D/F service.

Frame Aerials

The frame aerial, which was the basis of all wireless D/F apparatus, was simply a pair of spaced open aerials given a common earth lead and coupled and connected to form a 'frame' or 'loop' aerial. In using this type of aerial the frame is rotated about a vertical axis and the position of minimum signal strength noted. The plane of the frame is then at right angles to the direction of the signal, and a scale of degrees enables the bearing to be read. The maximum position, when the frame is in line with the signal, could just as readily be used, but the human ear is not always able to detect small differences in the intensity of a signal, whereas it is well able to choose the point where a signal is weakest, or inaudible. Since all early D/F was done by aural methods, the principle of the minimum signal for D/F purposes became established.

Bellini-Tosi

A very high degree of amplification was required with rotating loop D/F because of the smallness of the loop diameter compared with the wavelength. High amplification inevitably resulted in an increase in the general noise-level of the receiver, with a consequent tendency to mask the minimum position of the frame, and large frame aerials became unwieldy, making the D/F process slower and more laborious. About 1907, the research workers Bellini and Tosi developed a D/F system using fixed frames, and for many years this system was practically standardised for all D/F ground stations. The chief advantage of the system was that, because the frame aerials were fixed, they could be made much larger than the rotating loop. The D/F process was carried out by a small swinging search coil in an instrument called a radiogoniometer, which, in conjunction with the two frame aerials, constituted the complete Bellini-Tosi system.

The Radiogoniometer

This had two fixed or stator coils which were mounted at 90 degrees to each other, each stator coil forming a part of one frame aerial circuit. Mounted centrally in the space between the stator coils was a small coil called the search coil, which was connected to the receiver. The search coil was in effect a small frame aerial within the electric field of the two stator coils. As it revolved, the E.M.F. induced in it varied as the E.M.F. induced in the two fixed frame aerials would vary if they could be rotated. A scale and pointer associated with the search coil spindle completed the action of the radiogoniometer.

Sensing and Fixing

Bearings taken by rotating loop or goniometer D/F were subject to a 180-degree uncertainty. If a minimum occurred at 135 degrees there was a second minimum at 315 degrees, the loop or search coil having then turned a half-circle. Generally an aircraft requesting D/F assistance knew its approximate position, the ground station knew its rough course and destination, and the 'sense' of a bearing was apparent. But for D/F stations to be able to give a reliable safety service to an aircraft in distress or uncertain of its position, it must be possible to determine which of the two bearings is the correct one. This determination of the correct bearing was known as 'sensing'. The 180-degree doubt arose through the symmetry of the figure-8 radiation pattern of the aerial, essential to direction-finding. Sense was obtained by switching in the E.M.F. induced in an open vertical-wire aerial to the same receiver and combining it with the loop or goniometer E.M.F., after the bearing had been taken. The two E.M.Fs. from the open aerial and the loop aerial or goniometer were then aiding one another for one position of the loop and in opposition for the other, the combination of the two giving one maximum and one minimum position instead of the two equal maxima and minima in the case of the loop or goniometer alone. When this process had been completed, the bearing was said to have been 'sensed'.

Fixing was the use of bearings from two or more stations to form an intersecting point at which the aircraft's position was said to be fixed. When three ground stations were used the intersecting point never coincided in practice, and the size of the triangle formed at the intersecting point represented the possible error of the fix. This triangle was sometimes known as the 'area of doubt', or the 'cocked hat'.

Errors in Direction Finding

The main sources of error, which affected both D/F loop work and bearings received from ground stations, were 'site error' (generally known as quadrantal error) and 'night effect'. There were other sources, such as coastal refraction and polarisation error, but these were the main ones which affected the development of direction finding between the wars. Solution of site error in ground stations lay mainly in the choice of a site as free as possible from all possible interference from conductors The only method of dealing with site error once it was found to exist was the preparation of an error chart from which observed bearings could be corrected. This was always done in aircraft, the chart being permanently attached to the loop scale. The compilation of this from observed bearings was known as calibration. The presence of night effect was known very early in the history of D/F. It was noticed that the apparent bearings of fixed stations went through astonishing variations, sometimes being more than 90 degrees out. On medium wavelengths these phenomena were found to occur during the period between dusk and dawn, the daylight hours being comparatively free from any irregularity. The errors coming under the heading of night effect could be attributed to one main cause—the spurious E.M.Fs. induced in the horizontal members of a frame aerial by ionospheric reflections. A long series of trials and experiments between the wars was aimed at the elimination of 'night effect'.

There were several other causes of error, most of which were associated with the fact that two rays might be received at the receiving station, one direct and the other reflected from the ionosphere. These errors were due to fading, skip distance, and scatter. But in most cases where D/F errors appeared, an experienced operator could judge the conditions and select the right moment for taking a bearing, or at least recognise that a bearing was unlikely to be accurate.

The Adcock Aerial System

This system was first proposed by Adcock during the First World War, and was later practically standardised for permanent ground D/F stations. The principle of the Adcock aerial was the removal of the top horizontal limb of the frame so that it was not affected by the received wave. This principle was applied to the Bellini-Tosi aerial system with radiogoniometer, and it greatly reduced night effect.

Civil Aviation D/F Development Plan 1934

In 1934 there were four permanent civil aviation D/F stations, those at Croydon and Manchester being Bellini-Tosi and those at Lympne and Pulham being Marconi-Adcock stations. Croydon was to be converted to Marconi-Adcock in due course and so in all probability was Manchester. The civil aviation development programme for 1935 was for nine mobile stations, sites for which would depend on the development of air routes. The probable sites were Portsmouth, Hull and Newtownards (which was already in position and operating), Plymouth, Birmingham, Aberdeen, the Orkneys, and Bristol. Other possible sites were Renfrew, Newcastle, Cardiff, Wick and the Shetlands. Eight new permanent stations were to be erected by 1938–1939, three of which would be converted mobile stations. The sites of the permanent stations would depend on the course of internal airline development, but one station was to be erected at Heston early in 1935, and other likely permanent sites were Portsmouth, Hull, Newtownards, Plymouth and Renfrew. In addition the Channel Islands' authorities intended to erect a Bellini-Tosi station in Jersey, and the installation of a station on the Isle of Man was planned by the local government. The final position in 1938/39 was to be twelve permanent stations and six mobile stations. All these stations were to be of the Adcock type, working on M/F. Abroad, D/F facilities on the civil air routes were greatly expanded during this period.

The trend of European opinion in civil aviation was against the use of long-range track beacons. They were not considered suitable for complicated networks of routes, and insufficient frequencies were available for an extensive beacon organisation in addition to the channels required for normal two-way communication. Civil D/F ground stations economically combined two-way communication with navigational assistance on the same wireless channel.

It was proposed, however, to experiment with ultra-high-frequency short-range beacons to facilitate the approaches to airfields from distances of 15 to 30 miles. Experience showed that the bulk of congestion on D/F channels was due to the number of bearings required by aircraft in the last stages of approach before landing. A short-range beacon was already in existence at Croydon, and if experiments were successful other civil airfields were to be similarly equipped.

APPENDIX No. 11

AIR STAFF MEMORANDUM No. 15, 1 JANUARY 1924

The Use of Radio Communication by Home Defence Bombing Squadrons

1. This very complicated and difficult subject has recently been receiving the attention of the Air Staff, and it has been decided that any comprehensive statement of policy would at the present time be premature, in view of the limited experience of the subject which has been gained.

It has, however, been decided to proceed on the following lines, with a view to finding out what results can be obtained from present-day apparatus in existing aircraft, and what line future development should follow. The position will be reviewed at the end of 1924.

2. One squadron, namely No. 207, is to be equipped as follows :—every aeroplane will be equipped with 'Wing coils' and the necessary wiring and fittings to enable it to carry simultaneously Wireless Telegraphy sending and receiving, with trailing aerial, and Radio Telephony sending and receiving, with fixed aerial. The instruments which will be provided for the squadron will be two-way wireless telegraphy for the leader and deputy leader, and radio telephony reception for all other aeroplanes. In addition, 100 per cent reserve of instruments on the above scale will be held, so that the squadron can carry on, in spite of crashes and damaged instruments, for 18 months.

The above decision will mean that the leader and deputy leader will carry wireless installations weighing 140 lb. and all other aircraft 40 lb.

The personnel establishment of this squadron must allow the leader and deputy leader to carry wireless operators who are also trained as aerial gunners.

When the squadron has been equipped it is to practise formation flying with the two aerials down, and also navigation by means of sending signals to the ground and receiving positions from the ground. It is also to practise navigation by means of the wing coils only.

Two W/T ground stations will be necessary to work with this squadron, and these will be at R.A.F. Stations.

3. The first of the new day-bombing squadrons which is formed complete, *i.e.*, does not have to train its own pilots, will be equipped as follows:

All aeroplanes will have wing coils and the wiring and fittings to enable them to carry simultaneously wireless telegraphy sending and receiving with trailing aerial, and radio telephony sending and receiving with fixed aerial. Instruments will be provided for this squadron to enable the leader and deputy leader to carry wireless telegraphy sending and receiving and radio telephony sending and receiving, and all other aeroplanes radio telephony sending and receiving. In addition, 100 per cent reserve of instruments on the above scale is to be ready by the time the squadron forms.

The squadron is to use its radio telegraphy to practise formation flying tactics and drill, and its wireless telegraphy in the same way as No. 207 Squadron.

Both No. 207 and the new squadron will report on the effects of the trailing aerial, and on navigation by both methods open to them, *i.e.* by wing coils and by sending to the ground stations.

4. In addition to the two squadrons mentioned in paragraphs 2 and 3 above, all two-seater day bombers are to be capable of carrying the instruments laid down for the new squadron in paragraph 3, and enough instruments are to be held in reserve to enable two additional day-bombing squadrons to be equipped on the same scale and with the same reserve as the new squadron.

5. From 1st June 1924, all aeroplanes of No. 7 Squadron will be equipped with wireless telegraphy sending and receiving and also with rotating coils for direction finding, if the Vickers Vimy will take them. Instruments will be provided for all aircraft in this squadron, and 100 per cent reserves will be held in addition.

6. As each of the next three new night-bombing squadrons is formed, it will be equipped in the same way as No. 7 Squadron, except that rotating coils will not be used. A reserve of 100 per cent of wireless telegraphy transmitters and receivers will be formed for each of these squadrons as it completes forming, but no more rotating coils will be ordered until further reports on the revolving beacon have been received.

7. For the future, every effort must be made to improve wireless apparatus in the following directions :—

(i) The trailing aerial must be done away with in all aeroplanes which may have to fly in formation.

(ii) The receiving range of instruments must be extended without increasing their weight.

(iii) The 'revolving beacon' method of direction finding must be pushed on with.

(iv) Telephony and telegraphy must be combined in one instrument if possible. Aeroplanes of the future must be designed to carry the combined set.

APPENDIX No. 12

AIR STAFF MEMORANDUM No. 40, FEBRUARY 1928

THE USE OF RADIO COMMUNICATION BY HOME DEFENCE BOMBER SQUADRONS

(Air Staff Memorandum No. 15 on the same subject issued on 1 January 1924, is hereby cancelled)

1. From the experience gained in radio communications in Home Defence Bomber Aircraft during recent years, it is clear that the apparatus required by Air Staff Memorandum No. 15 to be fitted to these aircraft is not altogether satisfactory. While the individual items could be made to carry out their correct functions, the installation of the whole was so complicated and cumbersome as to interfere with the other duties of the crew of the aircraft.

It has been decided, therefore, to proceed on the following lines, until sufficient experience has been gained with the improved apparatus as to enable the final policy on this subject to be declared.

2. A. **Day Bombers**

(i) *New Apparatus.* A combined set capable of providing two-way W/T or two-way R/T, to operate on a fixed aerial, is to be produced for Service trials as soon as possible.

(ii) Until this apparatus is produced and given trials in a Service squadron, no definite decision as to the tactical use and employment of wireless in day-bomber aircraft can be made.

(iii) For the present all day-bomber aircraft are to be wired to take, and three per squadron fitted with, two-way W/T only, to enable the squadrons to practise D/F navigation by ground D/F (Bellini-Tosi) and two-way W/T communication with the ground and with other aircraft.

(iv) In addition to (iii) above, one flight of No. 100 (B) Squadron is to be equipped with two-way R/T of the same type as that now in use in No. 41 (F) Squadron to enable experience to be gained in the tactical handling of bomber formations using R/T.

(v) In specifications for future day-bomber aircraft, details of the wireless to be carried is to be omitted, but a space of specified dimensions to be allowed in the aircraft for wireless apparatus. These dimensions are to be arrived at now by the Royal Aircraft Establishment and are to be of a size to ensure that the new apparatus ((i) above) under development for this type of aeroplane can be carried.

B. **Night Bombers**

(i) A new W/T receiver capable of use for two-way W/T or wing coil reception is to be completed at an early date and given Service trials in a night-bomber squadron, with a view to its general introduction when proved satisfactory into all night bomber aircraft.

(ii) All future night-bomber aircraft are to be fitted with wing coils.

(iii) All present night-bomber aircraft are to continue to be fitted with two-way W/T to enable practice to be carried out in navigation by ground D/F method (Bellini-Tosi) and two-way W/T communication with the ground and other aircraft.

APPENDIX No. 18

MEMORANDUM ON THE USE OF D/F AS AN AID TO NAVIGATION AND DISSEMINATION OF INFORMATION OBTAINED FROM D/F SOURCES, 24 MARCH 1940

PART I

D/F as an Aid to Navigation

General

1. Successful air navigation is based upon Dead Reckoning, which consists of calculating the track and ground speed of an aircraft. Accurate navigation over long distances cannot, however, be maintained by Dead Reckoning alone, due primarily to the inability of meteorologists to forecast accurately wind velocities over wide areas.

2. Although Dead Reckoning must remain the basis of all navigation, navigators can resort to assistance from one of the following navigational aids :—

(i) Observation of objects on the ground.

(ii) Calculation of position lines obtained from the observation of celestial bodies.

(iii) Position lines or fixes obtained from radio.

(iv) The combination of any of the above.

3. Experience has shown that the mastery of any one of these aids alone is not enough accurately to conduct the navigation of an aircraft in all circumstances. It is therefore essential that navigators should appreciate the advantages and disadvantages of all possible aids to navigation. It is essential to bear in mind that the value obtained from astronomical position lines or radio bearings, or a combination of both, is almost invariably dependent upon the accuracy of Dead Reckoning navigation.

4. In astronomical navigation, Dead Reckoning positions may be comparatively inaccurate, but recent experience has shown that positions and bearings obtained by D/F methods are liable to grave inaccuracies, and that unless the D.R. navigation is carefully conducted, crews may easily be led into difficulties.

Necessity for Checking D/R by Loop Bearings, Astro and D/F

5. The navigator may frequently receive fixes and bearings which appear to show his D/R navigation grossly in error. These incorrect bearings or fixes may be due to misleading transmissions from the enemy, night effect, coastal refraction or the distance from the ground station combined with the height of the aircraft. Where efficient D.R. navigational methods have been followed, a navigator will be confident of his approximate position. He can then use D/F information with reserve, and reject such information as is manifestly inconsistent with his D.R. reckoning.

6. The navigator should constantly check his track and ground speed by observation of the ground where possible, or alternatively by astronomical means and by D/F, when these are available. He will then have a fair knowledge of the reliability of his sextant, of the reliability of the various D/F stations and beacons, of the W/T set, of the calibration of the loop and of the static condition of the atmosphere.

Errors likely to be Experienced when using D/F

7. The degree of error likely to be experienced on M/F D/F is dependent upon the efficiency of the ground personnel in obtaining a well-defined minimum, but experience has shown that a high degree of accuracy can be expected up to 250/300 miles, so long as the aircraft is high. It must be remembered, however, that one degree of error in the bearing will mean an error of approximately one mile at sixty miles range, the error increasing in proportion to the range. Similarly, the error in a fix when both bearings are incorrect will increase with the range. On the other hand, the H/F D/F system is only accurate up to a distance of 100 miles.

APPENDIX No. 12

AIR STAFF MEMORANDUM No. 40, FEBRUARY 1928

THE USE OF RADIO COMMUNICATION BY HOME DEFENCE BOMBER SQUADRONS

(Air Staff Memorandum No. 15 on the same subject issued on 1 January 1924, is hereby cancelled)

1. From the experience gained in radio communications in Home Defence Bomber Aircraft during recent years, it is clear that the apparatus required by Air Staff Memorandum No. 15 to be fitted to these aircraft is not altogether satisfactory. While the individual items could be made to carry out their correct functions, the installation of the whole was so complicated and cumbersome as to interfere with the other duties of the crew of the aircraft.

It has been decided, therefore, to proceed on the following lines, until sufficient experience has been gained with the improved apparatus as to enable the final policy on this subject to be declared.

2. A. **Day Bombers**

(i) *New Apparatus.* A combined set capable of providing two-way W/T or two-way R/T, to operate on a fixed aerial, is to be produced for Service trials as soon as possible.

(ii) Until this apparatus is produced and given trials in a Service squadron, no definite decision as to the tactical use and employment of wireless in day-bomber aircraft can be made.

(iii) For the present all day-bomber aircraft are to be wired to take, and three per squadron fitted with, two-way W/T only, to enable the squadrons to practise D/F navigation by ground D/F (Bellini-Tosi) and two-way W/T communication with the ground and with other aircraft.

(iv) In addition to (iii) above, one flight of No. 100 (B) Squadron is to be equipped with two-way R/T of the same type as that now in use in No. 41 (F) Squadron to enable experience to be gained in the tactical handling of bomber formations using R/T.

(v) In specifications for future day-bomber aircraft, details of the wireless to be carried is to be omitted, but a space of specified dimensions to be allowed in the aircraft for wireless apparatus. These dimensions are to be arrived at now by the Royal Aircraft Establishment and are to be of a size to ensure that the new apparatus ((i) above) under development for this type of aeroplane can be carried.

B. **Night Bombers**

(i) A new W/T receiver capable of use for two-way W/T or wing coil reception is to be completed at an early date and given Service trials in a night-bomber squadron, with a view to its general introduction when proved satisfactory into all night bomber aircraft.

(ii) All future night-bomber aircraft are to be fitted with wing coils.

(iii) All present night-bomber aircraft are to continue to be fitted with two-way W/T to enable practice to be carried out in navigation by ground D/F method (Bellini-Tosi) and two-way W/T communication with the ground and other aircraft.

APPENDIX No. 13

MEMORANDUM ON THE USE OF D/F AS AN AID TO NAVIGATION AND DISSEMINATION OF INFORMATION OBTAINED FROM D/F SOURCES, 24 MARCH 1940

PART I

D/F as an Aid to Navigation

General

1. Successful air navigation is based upon Dead Reckoning, which consists of calculating the track and ground speed of an aircraft. Accurate navigation over long distances cannot, however, be maintained by Dead Reckoning alone, due primarily to the inability of meteorologists to forecast accurately wind velocities over wide areas.

2. Although Dead Reckoning must remain the basis of all navigation, navigators can resort to assistance from one of the following navigational aids :—

(i) Observation of objects on the ground.

(ii) Calculation of position lines obtained from the observation of celestial bodies.

(iii) Position lines or fixes obtained from radio.

(iv) The combination of any of the above.

3. Experience has shown that the mastery of any one of these aids alone is not enough accurately to conduct the navigation of an aircraft in all circumstances. It is therefore essential that navigators should appreciate the advantages and disadvantages of all possible aids to navigation. It is essential to bear in mind that the value obtained from astronomical position lines or radio bearings, or a combination of both, is almost invariably dependent upon the accuracy of Dead Reckoning navigation.

4. In astronomical navigation, Dead Reckoning positions may be comparatively inaccurate, but recent experience has shown that positions and bearings obtained by D/F methods are liable to grave inaccuracies, and that unless the D.R. navigation is carefully conducted, crews may easily be led into difficulties.

Necessity for Checking D/R by Loop Bearings, Astro and D/F

5. The navigator may frequently receive fixes and bearings which appear to show his D/R navigation grossly in error. These incorrect bearings or fixes may be due to misleading transmissions from the enemy, night effect, coastal refraction or the distance from the ground station combined with the height of the aircraft. Where efficient D.R. navigational methods have been followed, a navigator will be confident of his approximate position. He can then use D/F information with reserve, and reject such information as is manifestly inconsistent with his D.R. reckoning.

6. The navigator should constantly check his track and ground speed by observation of the ground where possible, or alternatively by astronomical means and by D/F, when these are available. He will then have a fair knowledge of the reliability of his sextant, of the reliability of the various D/F stations and beacons, of the W/T set, of the calibration of the loop and of the static condition of the atmosphere.

Errors likely to be Experienced when using D/F

7. The degree of error likely to be experienced on M/F D/F is dependent upon the efficiency of the ground personnel in obtaining a well-defined minimum, but experience has shown that a high degree of accuracy can be expected up to 250/300 miles, so long as the aircraft is high. It must be remembered, however, that one degree of error in the bearing will mean an error of approximately one mile at sixty miles range, the error increasing in proportion to the range. Similarly, the error in a fix when both bearings are incorrect will increase with the range. On the other hand, the H/F D/F system is only accurate up to a distance of 100 miles.

8. Loop bearings are generally not as accurate for a given distance as are those of ground stations. The order of accuracy is certainly not more than plus or minus 2 degrees at 200 miles. They are especially affected by night effect during sunrise and sunset periods at distances over 50 miles from a beacon. It is important to bear in mind that the accuracy of the bearing is dependent upon accurate course keeping at the time of taking the bearing.

Availability of D/F Methods

9. It will therefore be appreciated that under certain conditions useful assistance from D/F may not be available. Consequently, the necessity for accurate D/R navigation is paramount, and all other means of navigation, especially for operational flying over enemy territory and over sea, must be considered as aids only to the accurate navigation of the aircraft.

PART II

DISSEMINATION OF INFORMATION OBTAINED FROM D/F SOURCES

Information regarding Position of Aircraft

1. The safety of aircraft, particularly in bad weather, will be enhanced if Groups and Stations are in possession of information regarding their movements. The position of aircraft is known

(*a*) from fixes or bearings given by D/F stations,

(*b*) from knowledge of the tracks flown out and home.

2. Stations should keep a listening watch on M/F D/F frequency whilst their aircraft are operating, and similarly on the M/F D/F identification frequency. Fixes intercepted on either frequency should be passed from the W/T receiving station to the Station Operations Room, thence to the Group Headquarters. Such fixes should be plotted at Stations and checked against the estimated D/R position.

3. Should doubt arise in the Operations Room as to the accuracy of a fix given, or if for any reason it is believed that the D/F Station is not answering aircraft transmissions, the Operating Station concerned should inform the Group. The Group Staff should then refer the query to the D/F Safety Section, or to the M.L.O., as appropriate. It should be noted that, in accordance with existing procedure, the M.L.O. passes all fixes obtained by the identification stations to the Group concerned.

4. If the safety D/F service is likely to be overloaded, the Group should communicate with the D/F Control Station, and indicate the order of priority to be observed in answering requests from aircraft of that Group. Similarly, Bomber Command Operations Room should be informed of any situation demanding that the Radio Beacon organisation may be brought into force, vide S.S.I., Part VI, Section 3.

5. In order that information is readily available, it is essential that known positions and estimated tracks are plotted. Only by such means will it be possible to make early decisions as to the best methods of assisting aircraft should this become necessary. In addition, such records will enable advanced information to be given to Regional Control Centres concerned, so that the latter may be prepared to accept aircraft at short notice.

Division of Responsibility between Groups and Stations

6. The responsibility for taking action and initiating queries rests with the Group and Station concerned. Stations must assist their own aircraft with the means at their disposal and a careful check is to be kept on the accuracy of their H/F D/F stations and the ranges at which their aircraft ask for bearings from them.

7. Group Headquarters are to start the Regional Control machinery when required, *e.g.* bad weather conditions, overloading of H/F D/F, or its failure to give efficient service. Stations should report immediately to the Group Headquarters if their H/F D/F system is unsatisfactory, or if the number of aircraft to be 'homed' is such that some may be delayed to the limit of their endurance.

Information obtainable from the Fighter Command Organisation

8. When aircraft are lost over this country and are unable to make use of D/F, for example owing to W/T failure, information as to their position may be obtained from Headquarters Fighter Command. If, therefore, it is known or may be assumed that an aircraft has crossed the coast under these conditions, the M.L.O. should be informed by the Group concerned. He will be able to keep the Group informed of the aircraft's position, as shown by the Observer Corps' plots, and will also take such action as the Group consider necessary for the lighting of aerodromes. Since the aircraft will be flying a left-handed triangular course it should be possible to determine that it is one of our own aircraft and to predetermine its track.

9. Advance information regarding the approach to the English Coast of aircraft which have failed to identify themselves may also be obtained from the M.L.O., but such information should be treated with reserve until the Observer Corps' plots are received.

Reliability of H/F/ D/F Organisation

10. Bearings given to aircraft by H/F D/F stations at distances over 100 miles are unreliable. All bearings given by these stations should be telephoned to the Station Operations Room, where they should be checked. If scrutiny shows a greater distance than 100 miles, the D/F station should be instructed to inform the aircraft that the bearing is unreliable, and a bearing or general direction passed to the aircraft on the instructions of Station Operations Room.

11. In addition to this known fault of H/F D/F stations, other circumstances, such as minor technical faults, may arise which will affect the accuracy of bearings given by them. To ensure a continual check on the accuracy of the D/F receivers, Groups are to arrange snap bearings by each D/F station on a known transmission, at intervals of not more than one hour.

Use of D/F Safety Services as Communication Channels

12. Existing orders lay down that aircraft engaged on night operations shall change to M/F from operational frequency when a point 100 miles from the English Coast is reached on the outward journey. Unless arrangements are made for aircraft to revert to operational frequency for short intervals and at predetermined times, this D/F channel is the only means of communication. It must, however, be realised that transmissions will interfere with the safety and navigational functions of the D/F Service.

Use of M/F D/F as an Aid to Navigation Outwards

13. When over 100 miles from the coast, a fix may be obtained from the M/F D/F Service allotted to the Group as a check on D.R. navigation. Care should be taken to ensure that interference is not caused to aircraft making use of the M/F D/F Service for safety purposes.

BC/S.20768/88/SIGS.

APPENDIX No. 14

ALLOCATION OF M.F. D/F SECTIONS, JUNE 1940

Section 'A.' *Inverness*—Sumburgh. (330 Kc/s)
Combined Security and Identification duties.
Identification Front :—57° 30′ N.–61° N.
Inverness connected by telephone to No. 14 Group M.L.S.

Section 'B.' *Renfrew No. 1*—Kirkwall-Sollas. (363 Kc/s)
Combined Security and Identification duties.
Identification Front :—55° 30′ N.–59° N.
Renfrew connected by telephone to No. 9 Group M.L.S.

Section 'C.' *Manchester No. 1*—Newtownards. (356 Kc/s)
Combined Security and Identification duties.
Identification Front :—55° N.–56° N. extending westwards to 8° W.
Manchester connected by telephone to No. 9 Group M.L.S.

Section 'D.' *Heston No. 1*—Hull No. 1–Newcastle No. 1. (348 Kc/s)
Security duties No. 5 Bomber Group aircraft.
Heston connected to Fighter Command M.L.S. by direct telephone.

Section 'E.' *Plympton*—Southampton (Old Netley). (314 Kc/s)
Combined Security and Identification duties.
Identification Front :—50° 30′ N.–48° N. and between 1° and 5° W.
Plympton connected to No. 10 Group M.L.S. by direct telephone.

Section 'F.' *Sealand*—Andover No. 1–Leuchars. (340 Kc/s)
Identification duties No. 4 Bomber Group aircraft.
Identification Front :—52° 45′ N.–56° 30′ N.
Sealand connected to Fighter Command M.L.S. by direct telephone.

Section 'G.' *Bircham Newton*—Lympne No. 2–Newcastle No. 2. (326 Kc/s)
Security duties No. 4 Bomber Group aircraft.
Bircham Newton connected to Fighter Command M.L.S. by direct telephone.

Section 'H.' *Tangmere No. 1*—Pulham No. 2–Carlisle No. 2. (273 Kc/s)
Identification duties No. 3 Bomber Group aircraft.
Identification Front :—50° N.–54° N.
Tangmere connected to Fighter Command M.L.S. by direct telephone.

Section 'J.' *Pulham No. 1*—Lympne No. 1. (257 Kc/s)
Identification duties No. 5 Bomber Group aircraft.
Identification Front :—50° 45′ N.–53° N.
Pulham connected to Fighter Command M.L.S. by direct telephone.

Section 'K.' *Hull No. 2*—Heston No. 2–Renfrew No. 2. (294 Kc/s)
Security duties No. 3 Bomber Group aircraft.
Hull connected to Fighter Command M.L.S.

Section 'L.' *Bristol*—Manchester No. 2–Tangmere No. 2–Exeter. (370 Kc/s)
Combined Security and Identification duties.
Identification Front :—50° N.–53° N. extending westwards to 8° W.
Bristol connected to No. 10 Group M.L.S.

Section 'M.' *Andover No. 2*—Manchester B/T–Western Zoyland B/T. (440 Kc/s)
Practice Group for use of Bomber O.T.Us., Coastal Command O.T.U. and School of A.A. Day watch (0800–1800 hours) only.

NOTE 1.—Stations in italics indicate Control Stations.

APPENDIX No. 15

HEADQUARTERS No. 1 GROUP SIGNALS INSTRUCTION No. 8, 25 May 1942

Signals Procedure for Aircraft on Operational Flights

1. The following procedure is to be used when aircraft of No. 1 Group are engaged on operational flights for which no special instructions have been issued.

Information to be carried in Aircraft

2. The wireless operator is responsible that the following are available in the aircraft :—

(i) F.398—W/T Operator's Log Book, which is to show a clean sheet at the start of each flight.

(ii) A.P. 982—Aircraft Operating Signals.

(iii) S.D. 0182/H.1—Aircraft and Ground D/F Verification Signals with sufficient extracts for the maximum possible duration of each flight only.

(iv) The schedule of operation of the British M.F. Beacons for the period covered by the flight.

(v) The operational call-sign allocated for the particular operation, the aircraft letter, and the M.F. D/F Section specifically allocated to the aircraft for the flight.

(vi) Standard destructible paper giving the following details :—

(*a*) The call-signs and frequencies of H.F. D/F stations in Bomber Command, and other stations to which the aircraft might be diverted in an emergency, viz. : those included in the Diversion Schedule.

(*b*) The call-sign of Group Headquarters, the collective call-sign of all Group aircraft in flight, and the Group Operational Frequency.

(*c*) The call-signs and frequencies (both D.F. and Guard) of Flying Control Centres.

(*d*) The diversion numbers set out in the Diversion Schedule for the period in force at the time.

(*e*) The call-signs and frequencies of the various M.F. D/F Sections, including their constituent stations.

(*f*) The station aircraft call-sign.

(*g*) The call-signs and frequencies of selected continental wireless stations.

3. The wireless operator is responsible that the transmitter click-stops are set up on the following frequencies :—

(i) High Frequencies :—
Base H.F. D/F.
Group Operational.

(ii) Medium Frequencies :—
M.F. D/F Sections E, F, G, H, J, and N.

The remaining click-stops may be set up according to local requirements.

4. The navigator is responsible that the following are available in the aircraft :—

(i) S.D. 02—Syko Machine with the correct card for the day.

(ii) A.P. 1927—Air Force Code.

(iii) An outline map showing pictorially the details of the Beam Approach Installations which are available on each stud setting on the receiver.

(iv) Location of British M.F. Beacons and continental wireless stations. These are to be on destructible paper.

Calibration Signals by Ground Stations

5. Station H.F. D/F will transmit call-signs for a period of 3 minutes at intervals of 15 minutes commencing at the clock hour, throughout the 24 hours. If, however, at the 15-minute intervals aircraft are being worked, call-signs will not be sent.

6. At every hour and half hour, commencing at the clock hour, throughout the 24 hours, the Group Medium Power Transmitter will transmit signals on the Group Operational Frequency in the following manner :—

(i) Where there is a message to be passed to aircraft :—

(*a*) Call-sign of all Group aircraft in flight or the Operational call-signs of the aircraft concerned (3 times).

(*b*) " V ".

(*c*) Call sign of Group (3 times).

(*d*) Text of message (twice).

(ii) Where there is no message to be passed to aircraft :—

(*a*) Call-sign of Group (3 times).

(*b*) Short Break.

(*c*) Identification numeral (once).

(*d*) Short Break.

(*e*) " V " (6 times).

Note.—The last sequency signal is to include a time signal and will be concluded by " VA ".

These signals will be transmitted for a period of at least three minutes, the sequence being repeated as necessary.

In order that there shall be no confusion with diversion numbers, only the numerals 1–9 are to be used as the identification numeral.

7. The control station of each M.F. D/F Section will transmit its call-sign for 3 minutes at 15 and 45 minutes past the hour daily, the first of such transmissions being at 11.15 B.S.T. and the last at 13.45 B.S.T. The transmissions will not be allowed to interfere with the operational function of the M.F. D/F Service, and if, at these intervals, aircraft are being worked, the call-signs will be curtailed or omitted as necessary.

Ground Control of Aircraft

8. The use of R.T. for the control of take-off is to be restricted and where other means of control are possible R.T. is not to be used. If, however, it is used, a short drill of essential signals only is to be employed and such practices as, for example, pilots requesting permission to take off before they have been instructed to do so, which only result in additional and unnecessary signalling by the control station, are forbidden.

Security

9. Strict W/T silence is to be observed at take-off and no W/T or R/T checks necessitating transmission are to be carried out.

10. It is emphasised that in the interests of security, transmissions from aircraft, either W/T or R/T, must be kept to the minimum consistent with safety.

11. All W/T transmissions to and from aircraft (with the exception of Diversion Signals and Recall Signals, which will be sent as laid down in paragraph 22 below) must be in SYKO, except in emergency upon the express instructions of the captain of the aircraft.

12. Radio Aids to Navigation should normally be obtained by means of D.F. Loop Bearings, Radio Track Guides, and Station Beam Approach Systems. Navigational aids requiring W/T transmission should only be used when absolutely necessary.

13. In addition to the loss of security caused by W/T or R/T transmissions, it is to be impressed on all crews that as the numbers of operational aircraft increase, the amount of navigational aid that can be given to aircraft using transmitters will be strictly limited, while on the other hand navigational aid obtainable by D.F. Loops and Beams is unlimited.

Navigational Aids Requiring W/T Transmission

14. (i) M.F. D/F Section F has been allotted to No. 1 Group and this is the section to which wireless operators should normally make distress calls, requests for assistance, and identification signals. In an emergency or when the aircraft is flying in an area in which their own section is unsuitable, wireless operators may work any other appropriate section.

(ii) Whenever S.O.S. calls, requests for D/F fixes, or identification signals are made, the control station of the appropriate section is to be worked. Bearings may, however, be obtained from any station in the M.F. D/F organisation.

15. (i) Short-range H.F. D/F stations are situated at most airfields and are available for homing purposes from distances up to 100 miles.

(ii) Normally aircraft should be at heights of not less than 4,000 feet when requesting bearings at ranges of more than 50 miles.

(iii) On no account are bearings to be obtained by aircraft which are more than 100 miles distant from the D/F station, since at these distances the D/F station is liable to lie in the skip area of the aircraft transmitter and the risk of large errors and reversed sense is very great.

16. Wireless operators must be prepared to give the correct verification signal from S.D. 0182/H1 should they be challenged by a ground station. Similarly, wireless operators should challenge a D.F. station if the transmission is considered to be of doubtful authenticity.

17. (i) The emergency R.T. Organisation "Darky" exists to enable the pilots of aircraft to obtain immediate R.T. communication with the ground.

(ii) All Bomber Command aerodromes and certain other aerodromes maintain continuous watch on a common frequency from dusk to dawn, and can establish immediate communication with any aircraft calling "Darky", so that assistance and information can be passed direct to the pilot.

(iii) These ground stations have an approximate range of 8 miles.

Balloon Barrage Warning Signals

18. Transmitters are installed at the majority of balloon barrages for the purpose of radiating a signal which produces an audible note in the aircraft R/T receiver similar to the warbling note of an air raid siren, to warn aircraft of the presence of a balloon barrage. The transmitter has a range of approximately 10 miles, but owing to various local conditions this may be considerably exceeded or reduced. Pilots of aircraft are to switch on the R/T receiver at all times when there is any possibility of their being in the vicinity of a balloon barrage.

Operational Control of Aircraft

19. Operational control of aircraft will be by Group Medium Power Transmitter and all aircraft are to listen on the Group Operational Frequency at the hour and 30 minutes past the hour for control signals, unless the aircraft is homing on H.F. D/F. If one half-hourly period is missed it is imperative that watch is kept at the next period.

20. These control signals will be broadcast and should not be acknowledged unless specific instructions to acknowledge are included in the address of the message. This instruction will consist of the insertion of the procedure signal "Y".

21. It is essential that the aircraft transmitter is accurately set up on the Group Operational Frequency.

22. Diversion and Recall Signals will not be put into SYKO but will be sent in the following form :—

(i) Diversion Signals.—Diversion signals will consist of BFX followed by the number of the airfield, taken from the current diversion schedule. Should it be necessary to divert aircraft of this Command to an airfield which is not included in the diversion schedule, the name, call-sign, frequency etc. of that airfield will be transmitted in clear.

(ii) Recall Signals.—Recall signals will consist of one of the following sets of groups from A.P. 1927 :—

NLW BBA—Abandon Operations and land at the Base.

NLW (Diversion Number)—Abandon Operations and land at (airfield indicated by diversion number).

NLW BJV (Diversion Number)—Abandon Operations and land at (airfield indicated by diversion number) or at any suitable airfield *en route* which will accept you.

Safety Precautions Over the Sea

23. During the period when aircraft are over the sea transmitters are to be adjusted to the appropriate M.F. D/F frequency (normally Section F) in order that no time may be lost should it be necessary to transmit a distress signal. This refers to transmitters only, and operators should change to the receiver frequency as necessary either to obtain navigational aid or to listen to the Group Routine Broadcasts.

Emergency Reports

24. The following self-evident code is to be used for the reasons indicated by the code if it is doubtful whether the aircraft will regain British territory :—

(i) FTR—Damaged by enemy fighter.

(ii) FLK—Damaged by enemy flak.

(iii) BAL—Damaged by enemy balloons.

(iv) ICE —Icing.

(v) ENG—Engine failure.

(vi) PET—Fuel shortage.

(vii) LLL—Lost.

25. The message should normally be addressed to Group and passed if possible on the Group operational frequency but may be passed on any medium D/F frequency or station D/F frequency. The message is to be given Emergency priority. In circumstances requiring the sending of S.O.S. the appropriate code group should if possible be added to the distress call.

26. It must be clearly understood that the use of this code must not jeopardise the passing of S.O.S. calls, either from the aircraft concerned or from other aircraft using the same frequency.

Identification by I.F.F.

27. All aircraft which are fitted with I.F.F. are to keep the device switched on using No. 1 Setting (Narrow) :—

(i) On the outward flight, from the time of take-off until the aircraft is 50 miles out at sea.

(ii) On the return flight from the time the aircraft is 100 miles from the coast until it has landed.

(iii) When within visual range of H.M. ships at sea or when H.M. ships are known or believed to be sailing in the area over which the aircraft is operating.

28. Aircraft fitted with I.F.F. are, whenever possible, to approach the coast of Great Britain at a height exceeding 2,000 feet above sea level.

29. Provided that the wireless operator has satisfied himself by tests that the I.F.F. device is working satisfactorily, identification by the procedure outlined in paragraph 32 below may be dispensed with if the aircraft is flying higher than 2,000 feet.

30. The attention of all wireless operators is to be drawn to the test to be carried out on the I.F.F. equipment during flight as laid down in A.P. 1766G, Volume 1, paragraph 14.

Identification by M.F. D/F Signals Procedure

31. The identification procedure detailed in paragraph 32 below is to be carried out by aircraft :—

(i) Which are not fitted with I.F.F.

(ii) Whose I.F.F. sets are not working correctly.

(iii) Which are flying below 2,000 feet above sea level ; or

(iv) Whose direction of approach is one which would not normally be followed, but which is occasioned by an error in navigation, or by orders received whilst airborne.

The identification signal described should be transmitted when the aircraft is as nearly as possible 60 miles from the coast on the return flight.

32. The identification procedure consists of sending a signal, in the form indicated below, on M.F. D/F Section F, or other appropriate section :—

(i) Call-sign of D/F Control Station—"V"—call-sign of aircraft.

(ii) Total number of aircraft in formation (if more than one).

(iii) A long dash of 15 seconds.

(iv) Call-sign of aircraft made once only.

33. When requiring a D/F fix or bearing from an M.F. D/F section aircraft are to use the same procedure as laid down in paragraph 32 (i) above, followed by the appropriate operating signal, a long dash of 15 seconds, and the call-sign of the aircraft made once only. For example :—

(i) Call-sign of D/F Control Station—"V"—call-sign of aircraft.

(ii) Operating signal requesting fix or bearing.

(iii) Long dash of 15 seconds.

(iv) Call-sign of aircraft made once only.

34. The Control Station will :—

(i) Answer the aircraft with letter "R" in the case of identification only ; or

(ii) Transmit the bearing of the aircraft, if a bearing has been asked for ; or

(iii) Answer the aircraft with the letter "R", if a position has been requested, and then, after a short pause, transmit the position of the aircraft ;

(iv) If the identity of the aircraft is in doubt, challenge by means of the S.D. 0182/H.1 procedure. If there is no reply to the challenge or if an incorrect reply is received, the Control Station will refer the matter to the appropriate M.L.S. for further instructions.

Identification of Aircraft in Distress

35. Aircraft in distress, that is to say, aircraft incapacitated either structurally or by weather conditions and in danger of failing to reach a base, are to make a distress call to the M.F. D/F Organisation, as indicated in sub-paragraph (ii) below, and, simultaneously, in aircraft fitted with I.F.F. the Code Switch is to be moved from No. 1 Setting (Narrow) to No. 3 Setting (Very Wide). A breakdown on either the aircraft W/T transmitter or the I.F.F. set should not prevent the other set from being used for this purpose.

36. A distress call should normally be made on the M.F. D/F section allotted to this Group, i.e. Section F, but may be made on any of the M.F. D/F Sections should congestion occur on Section F. Whenever such calls are received the resultant fixes and the particulars of the aircraft concerned will be passed immediately to the

M.L.S. to which the Control Station of the Section is connected. The Control Station concerned will thereafter give priority facilities to the aircraft in distress. An aircraft after transmitting its distress message is to endeavour to send its call-sign for a period long enough to permit D/F Stations to determine its position.

37. A special watch will be kept on the track of any aircraft showing "Very Wide" I.F.F. (No. 3 Setting), and all details of its track passed to the M.L.S. The M.L.S. will take action as laid down in the instructions for the Air/Sea Rescue Organisation, in addition to informing Group Headquarters to which the aircraft belongs.

Identification of Aircraft being Shadowed by the Enemy

38. Warning that the aircraft is being shadowed by enemy aircraft is to be given by adding a special code group to the identification signal which is transmitted in accordance with paragraph 32 above. The code groups concerned are given in A.P. 1927 and are as follows :—

GCN—Enemy aircraft in company with me.
GCB—Unrecognised aircraft in company with me.

Whenever one of the above groups is used it is to be followed by the number of aircraft to which it refers, e.g. :

H7X —Aircraft call-sign.
6 —Total number of aircraft covered by the signal.
GCN9 —Nine enemy aircraft in company with me.
H7X —Long dash of 15 seconds followed by call-sign made once only.

Note.—When making the above transmission extreme care is to be taken not to interfere with other aircraft transmitting.

39. The D/F Control Station will acknowledge receipt of the transmission by sending the letter "R". If the first transmission is not acknowledged by the D/F Control Station a second transmission is to be made at the first opportunity.

Landing Signal

40. On arrival in the vicinity of the parent station or any other station to which an aircraft has been diverted, the pilot is to establish communication with the Watch Office by R/T for the purpose of obtaining permission to land or receiving any instructions from the airfield Control Officer.

41. After landing, the pilot is to inform the Watch Office by R/T that he has landed, in order that the airfield Control Officer may know exactly what aircraft are still airborne.

42. In the interests of security NO signal of any description is to be made by W/T which would indicate that the aircraft is about to land, either by "X" signal (X195) or by local arrangement (such as VA VA).

43. Weather reports when passed by R/T must be confined to the terms "FIT" "FIT ZZ" "UNFIT". The definition of these terms is given in A.M.C.O. A.20 of 1940.

44. The decision whether barometric pressure should or should not be given on any particular occasion is to rest with the Station Commander concerned.

Responsibility of Wireless Operators

45. No signals are to be made at any time without the permission of the captain of the aircraft. Operators are to keep captains of aircraft informed at all times of the stations with which they are in communication or with which they are able to establish communication.

46. *The Captain of the aircraft is to be informed immediately should a W/T failure occur.*

(Signed) Group Captain
Senior Air Staff Officer,
Headquarters, No. 1 Group