THE SECOND WORLD WAR

1939–1945

ROYAL AIR FORCE

ARMAMENT

VOLUME II

GUNS, GUNSIGHTS, TURRETS, AMMUNITION AND PYROTECHNICS

Promulgated for information and guidance of all concerned.

By Command of the Air Council,

J. H. Barnes.

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GUNS, GUNSIGHTS, TURRETS, AMMUNITION AND PYROTECHNICS

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CHAPTER 1

FUNDAMENTAL TYPES OF GUN ACTION AND DEVELOPMENTS UP TO 1935

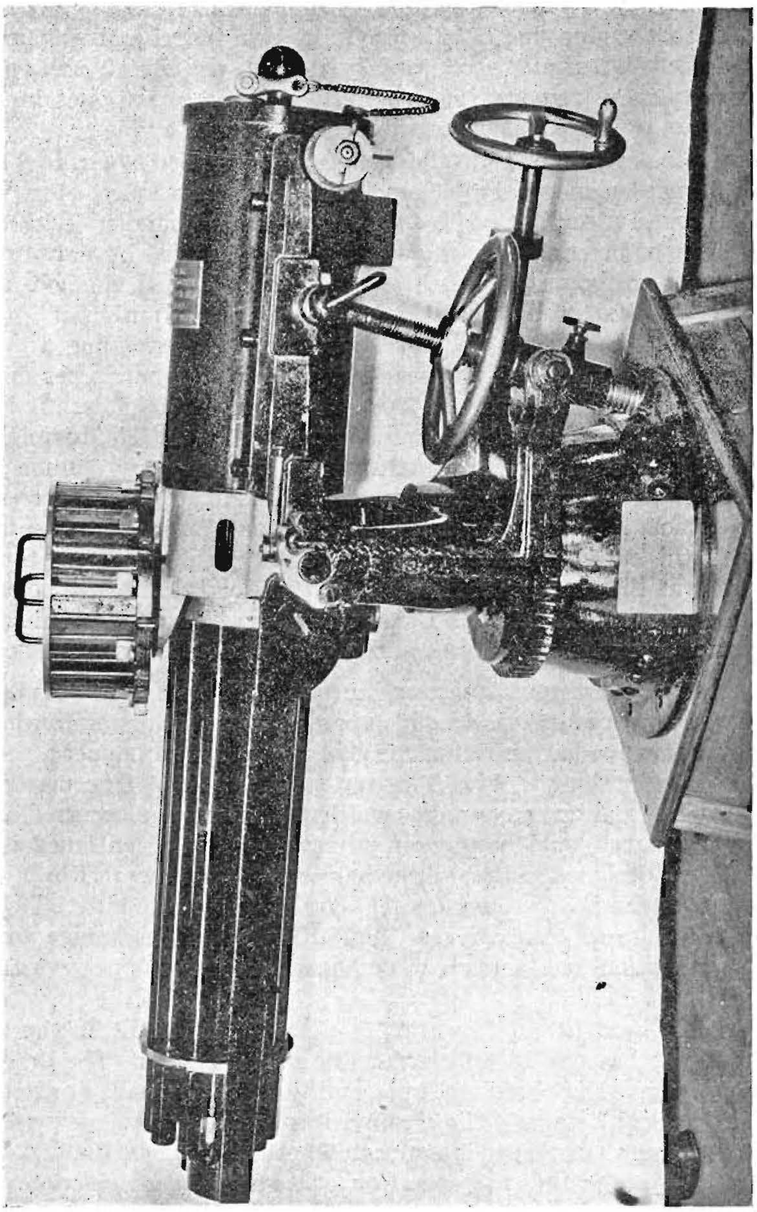
Early history

The first effective gun for rapid fire was the *Mitrailleuse*, designed in Belgium in 1851. It had several barrels mounted round a common axis and was operated by a crank lever. Early versions of the gun had 37 barrels, but this was reduced to 25. Barrels were rifled and accurate up to 500 yards. The rounds were held in perforated plates which fitted into grooves at the rear of the gun and locked the breech, so that each round lined up with its own barrel and was fired by turning a handle. When all barrels had been fired, the breech was opened, plate and empty cases removed, and a fresh plate and cartridges inserted. With a good team twelve plates of cartridges could be fired a minute.

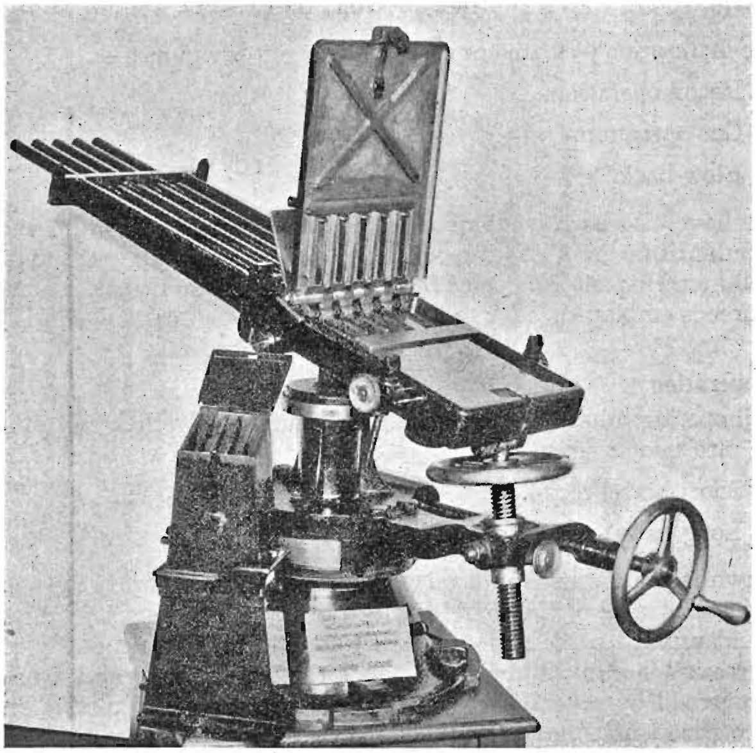
The next step in development was the Gatling gun, invented by Dr. Richard J. Gatling—a Chicago engineer. It had several barrels, from four to ten, which were revolved round a central axis by turning a cranked handle. Each barrel had its own bolt or breech block, the ammunition being fed by gravity by a stationary hopper on top of the breech. As the barrels turned, the bolt moved in cam grooves, picked up a round from the hopper, and pushed it into the chamber; the round was fired and case extracted, thus providing a type of automatic feed. The rate of fire was approximately 350 rounds per minute, and much depended on how fast the operator turned the handle. If it was turned too fast, the gun was liable to mechanical stoppages. The barrels, each complete with its breech block made the gun very heavy and cumbersome. The first Gatling guns were used in British operations in 1879, but success was limited due to lack of mobility and tendency to jam at critical moments. In common with the early machine guns, the Gatling suffered from the disadvantage that at the time of its introduction, the solid drawn cartridge case had not been perfected. The British Boxer cartridge which was then in general use had a paper case with metal base, and was unsuitable for machine guns.

About that time numerous inventors turned their attention to machine guns, but the most successful was a London banker named Thorsten Nordenfelt. His gun had two or five barrels in line fed by gravity from a hopper; the gun being operated by pushing a lever backwards or forwards. The mechanism was very accessible and one advantage was that if a stoppage occurred in any one barrel, that barrel could be put out of action and fire continued on the remainder. It was designed so that all the barrels could fire together or in quick succession, rate of fire being approximately 350 rounds per minute. This gun adopted the solid drawn cartridge case, and although full advantage was not taken of this invention, one immediate outcome was that stoppages were less frequent.

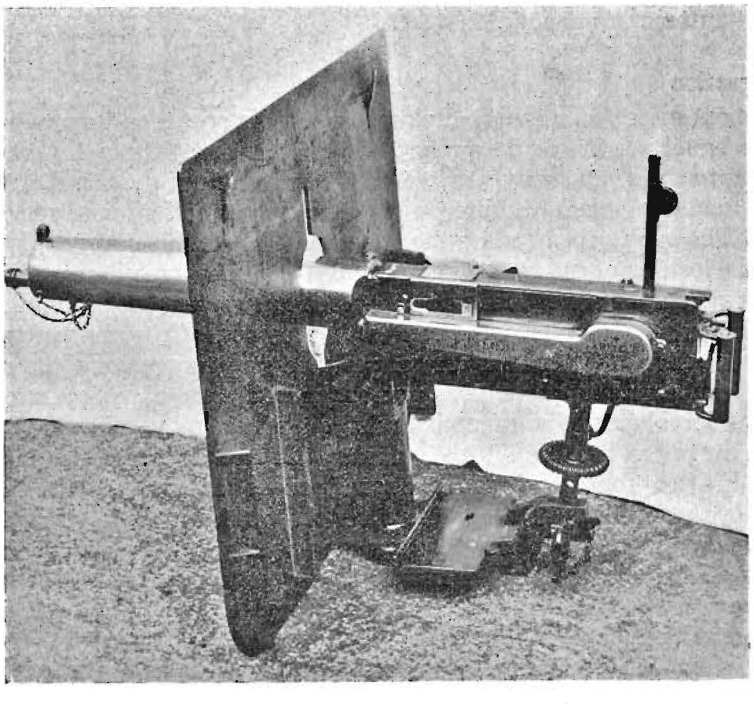
The year 1883 brought the invention of a gun by Hiram K. Maxim which was to become the basis of all fully automatic machine guns. The principles Maxim laid down have since been used successfully with practically no alteration except in mechanical details. The weapon introduced several new features which it had not been possible to incorporate in other guns. In the first place, the gun was fully automatic, the operation of extraction and ejection of the empty cartridge case, feed and firing, being performed automatically by the gun itself. The barrel was 'free' in the casing and could move to the rear on recoil, and, working through levers and springs, brought about the complete action of loading and firing the gun. The rate of fire was approximately 600 rounds per minute. Another feature was the replacement of a number of barrels by a single one, and to keep the barrel cool it was encased in a jacket containing water. Gravity feed had been a source of trouble in all previous machine guns, so Maxim introduced the well-known belt feed in which the belt containing the ammunition was moved across by the action of recoil in time with the other movements. The Maxim gun was introduced into the British Army in 1891, and soon replaced other machine guns.



GATLING MACHINE GUN



NORDENFELT ·45-INCH MACHINE GUN



MAXIM MACHINE GUN

Types of Gun Action

Three main principles are employed in present day guns :—

(*a*) Recoil operation.

(*b*) Gas operation.

(*c*) Blow-back.

There have also been combinations of these systems. The first and second were combined in the Vickers recoil and ·30 Browning gun, second and third in the 20-mm. Hispano, and since the introduction of the B.F.M., a combination of all three is employed.

Recoil operation

Recoil operation has been employed more universally than any other. It is divided into two groups :—

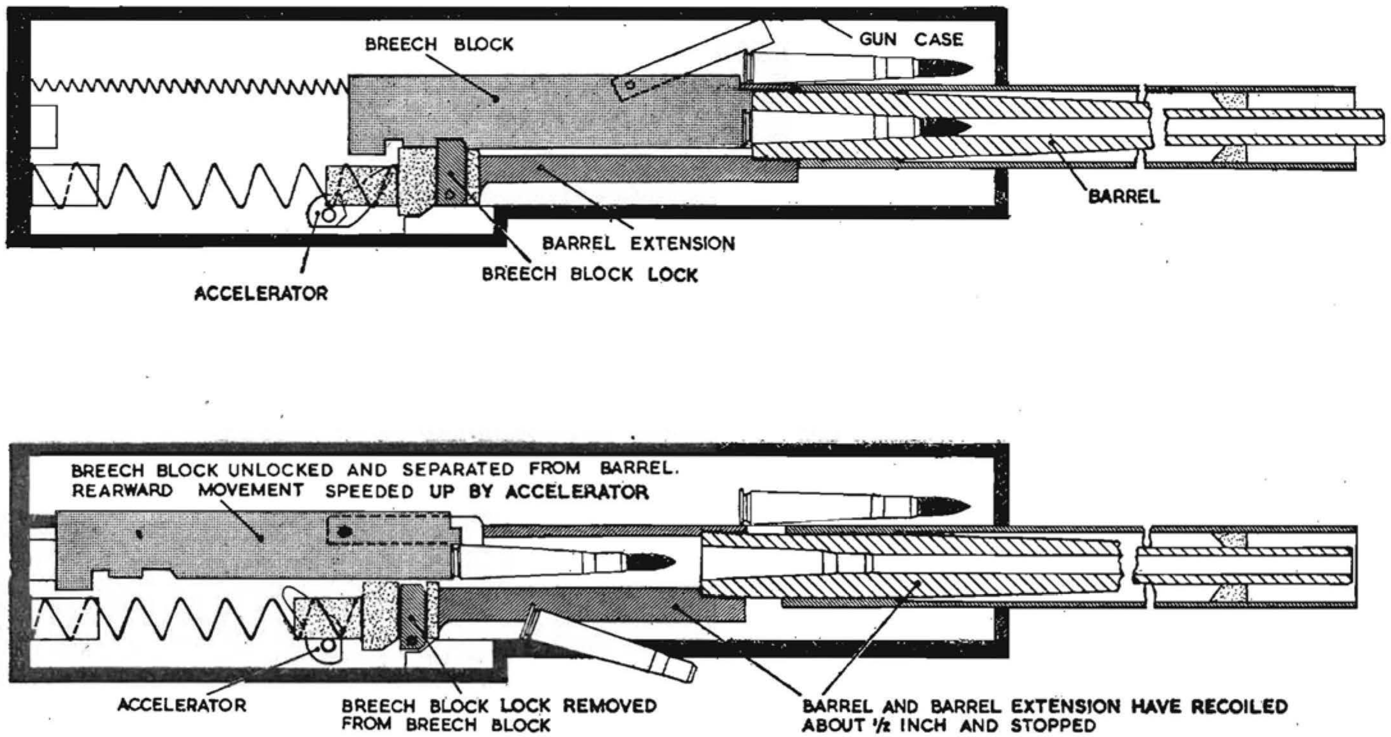
(*a*) Short barrel recoil.

(*b*) Long barrel recoil.

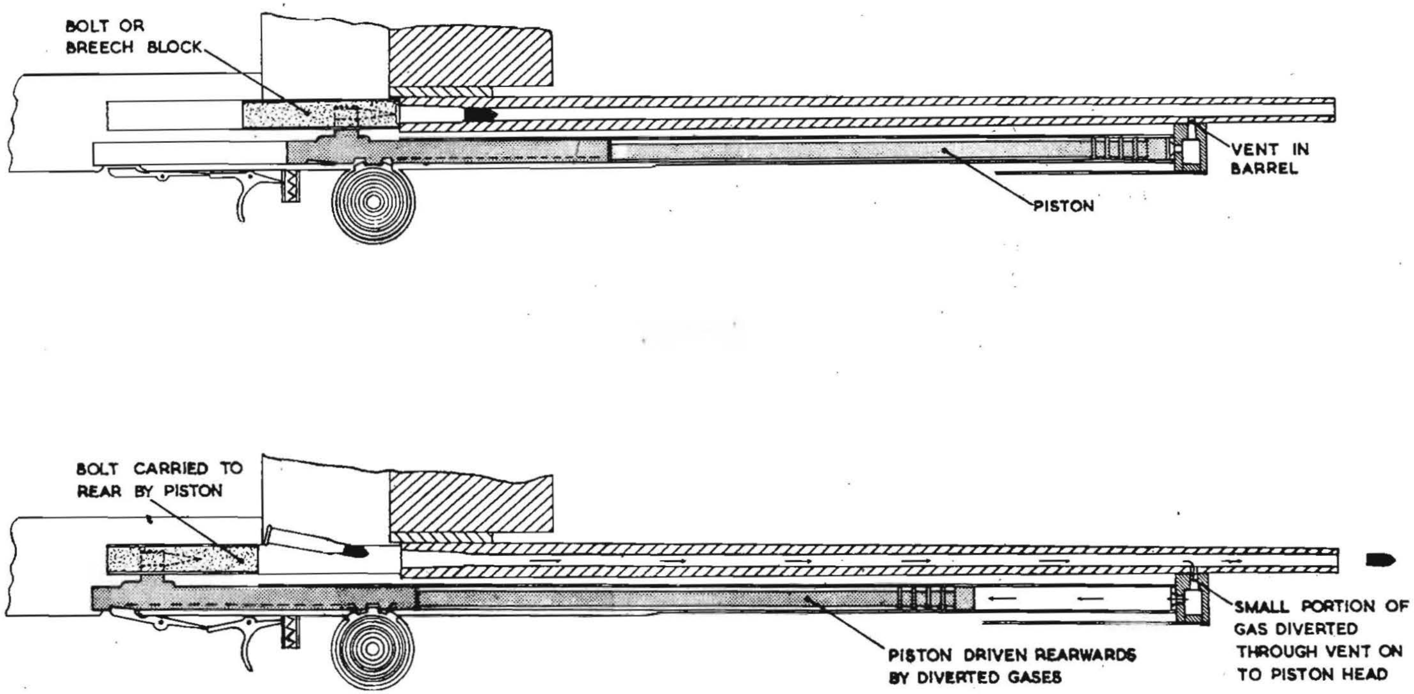
The two terms are used in a relative sense. In the short recoil movement, the backward travel of the barrel is much less than the length of the complete round and usually in the region of half to one inch. With the long recoil, the barrel moves for a much greater distance than the short recoil—the distance being governed by several factors—but must be greater than the length of a complete round of ammunition to enable feed to take place on the forward movement. Short barrel recoil is used in the Maxim, Vickers recoil and Browning guns, long barrel recoil in 37-mm. C.O.W. and 40-mm. 'S' guns. Long recoil has been used on smaller calibre guns, but is not generally favoured for light automatic weapons.

Gas operation

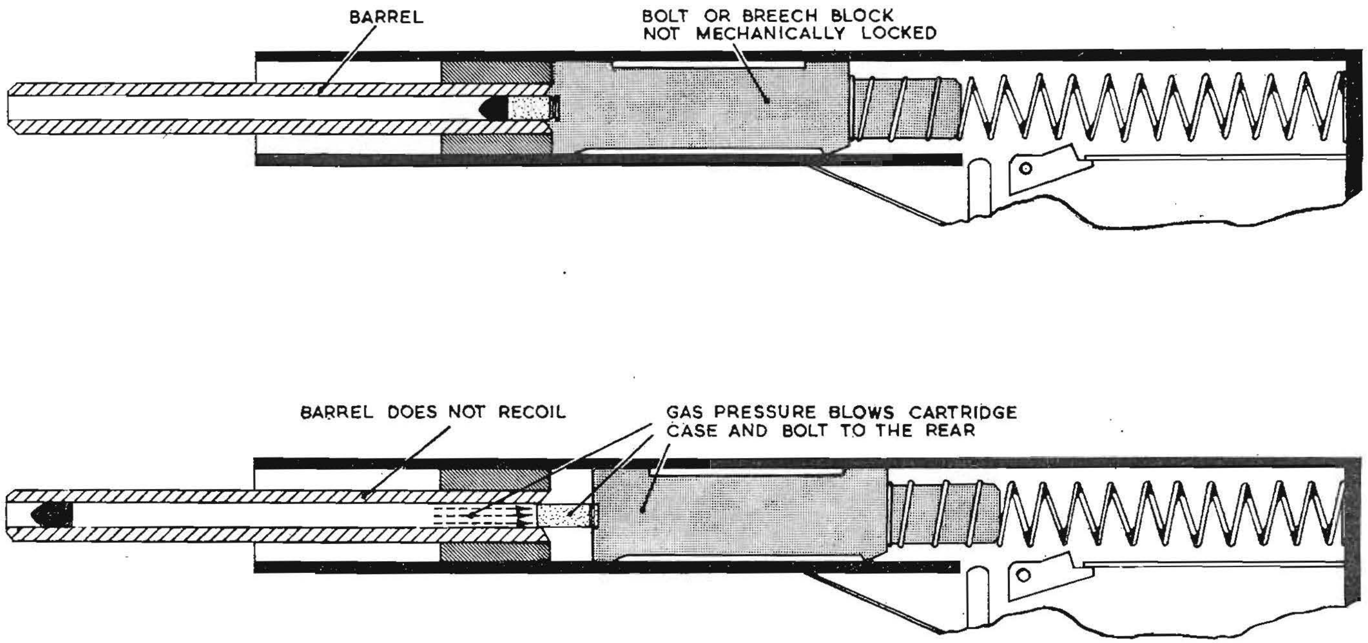
The most successful method employed in the gas operation principle is that in which a small portion of the propellent gas is diverted through a vent in the barrel on to a piston usually situated on the underside of the barrel. The piston is thus made to unlock the breech block, move it to the rear and compress a spring. The spring then carries the piston and breech block forward and completes the loading of the gun. The amount of gas energy required to be diverted to carry out the operation is so small that it has no material effect on the velocity of the bullet. The important factor is the position of the vent in the barrel. This is determined by the amount of gas necessary to overcome the resistance offered by the moving parts. One point against the use of gas operated guns is the considerable amount of carbon deposit which may collect in the vent, around the piston head and in the cylinder. This necessitates constant cleaning especially after prolonged firing, as it soon hardens and has to be chipped off. In favour of this system is the fact that the gun can be made much lighter than recoil operated guns, because the parts are not subjected to such heavy initial pressures, but only to those pressures acting on the piston which are only a small part of the initial pressure. But the gun does not lend itself readily to belt feed as there is not the reserve of power to operate the extra components necessary for the feed mechanism, and to lift heavy lengths of belt.



Short Barrel Recoil Operation



Gas Operation Principle



DIRECT BLOW-BACK PRINCIPLE

Blow-back operation

The blow-back method of operation depends entirely on the momentum given to the breech block by the projected cartridge case. The movement of the breech block must be delayed so that the bullet will have left the muzzle before any appreciable opening occurs between the breech and barrel, otherwise gas will escape to the rear and will endanger the firer and lower the velocity of the bullet. This delaying action may be brought about by one of three methods :—

(*a*) The method in which the locking of the breech block is direct and unlocking takes place through the medium of a short stroke gas piston as in the 20-mm. Hispano gun.

(*b*) A retarded locking system, either using friction or resistance of springs. This method is used in the Thompson sub-machine gun.

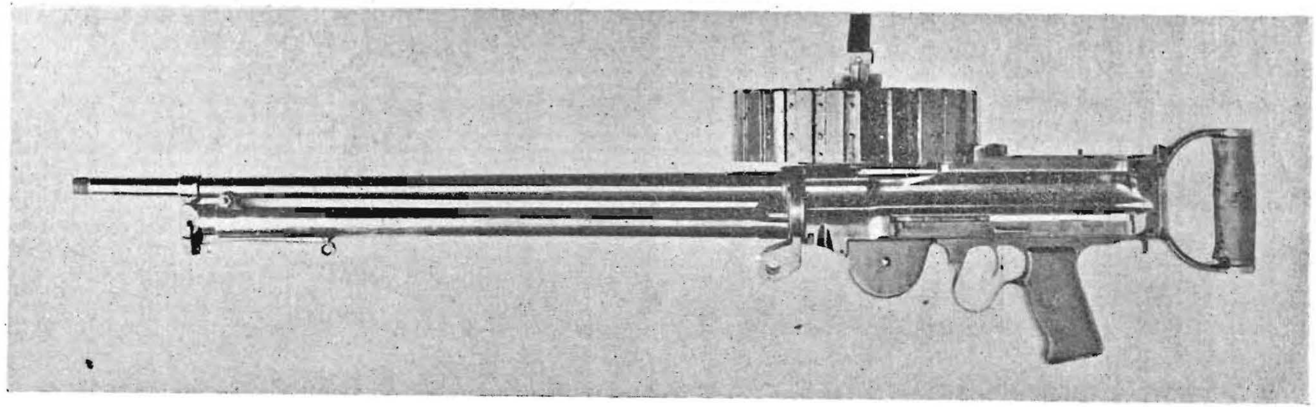
(*c*) A method using an exceptionally heavy breech block and other moving parts to give the necessary delay before the breech is opened as in the Sten machine gun.

In all three systems the cartridge case is used as the medium for pushing the breech block to the rear. When it starts to move back, a portion of the case is unsupported by the chamber and the cartridge case must, therefore, have specially thick walls at this point to prevent bursting of the case.

The blow-back system of operation is not generally favoured in machine guns because of the extremely heavy parts usually necessary to delay the action and ensure safety, and the heavy spring sometimes needed to absorb the movement of the heavy parts. Some guns employed during the Second World War used this principle though this was mainly because of the ease of production brought about by simplicity of design. Many of the numerous and complicated components necessary with other systems were no longer required.

At the outbreak of the First World War military aircraft had very little spare lifting capacity for weapons, and these consisted entirely of revolvers or service rifles, or sporting guns firing chain shot. The need for improved armament was immediately apparent. Experiments were made in two-seater pusher aircraft, in which a Lewis infantry machine gun was mounted for use by the observer who sat in front of the pilot. These were standard infantry guns with an aluminium alloy radiator surrounding the barrel, and they utilised the 47-round magazine. As the war progressed, these guns were gradually stripped of their radiators and other non-essential parts in the aircraft version of the gun, and they were also modified to give a higher rate of fire. A 97-round magazine was also developed to reduce the ' dead ' time due to magazine changing during combat.

Tractor aeroplanes soon began to supersede the pusher types, as the former gave a better performance. There was one serious disadvantage from the armament point of view—the gun had to be mounted to fire outside the plane of



Lewis Machine Gun

rotation of the propeller to avoid damage to the blades. Numerous types of mounting were evolved :—

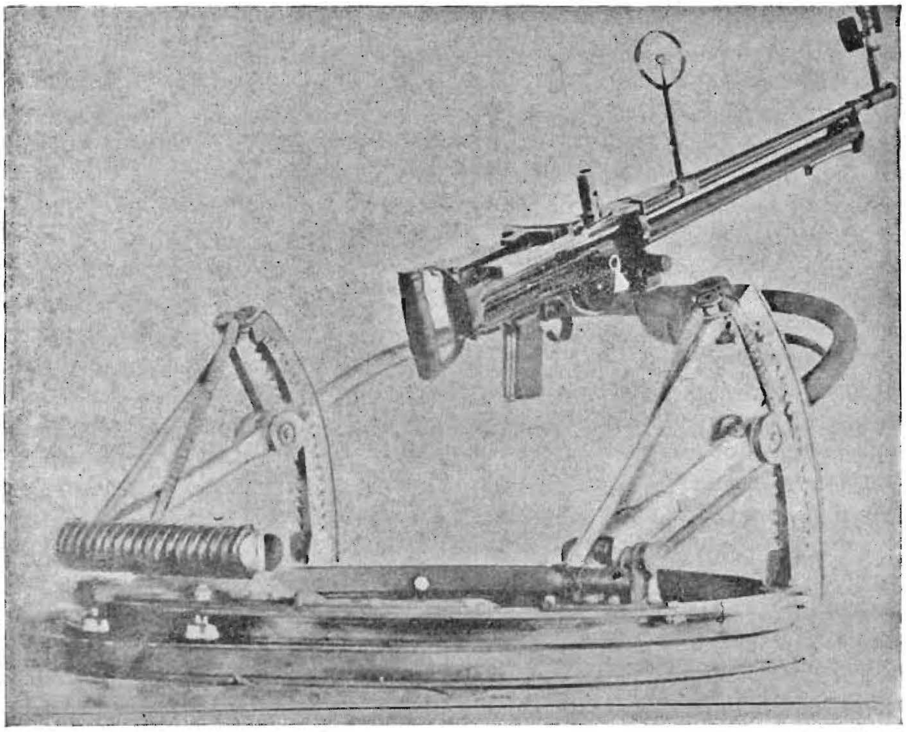
(*a*) Gun mounted on the wing, firing along the line of flight. The trouble with all wing mountings, however, was that the guns were not reliable, and too many stoppages occurred which could not be cleared. Magazine fed guns had to be used because of the lightness, but these had a limited ammunition supply.

(*b*) Gun mounted on the wing, but inclined outward to the line of flight. Although some of these guns were accessible and could be re-loaded and stoppages cleared, it was impracticable to aim accurately when flying in one direction and aiming and looking in another.

(*c*) Gun mounted on top centre section. The Lewis gun in this installation was mounted on top of the centre section of the wing and could be pulled down a curved ramp to enable the pilot to clear stoppages or re-arm.

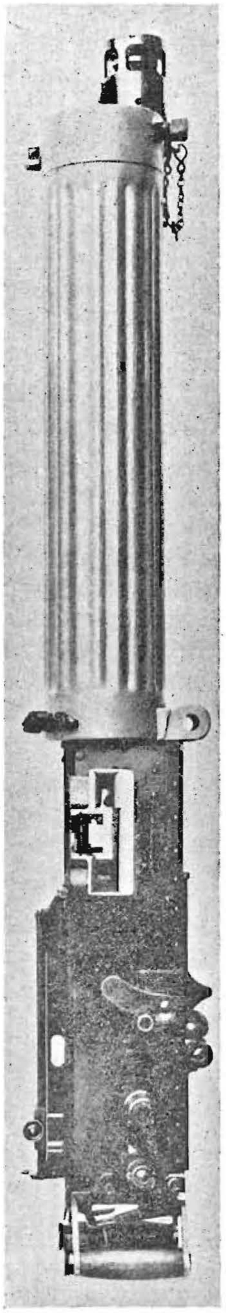
(*d*) Gun mounted through centre section, firing at about 30 degrees elevation. This mounting was, perhaps, the best of all, in that on firing upwards the fighter did not have to climb up to or above the enemy. In this way time was saved in the attack, and for the speeds of attack at that period a true ' no allowance ' shot was presented, requiring only point blank aim by the pilot.

The gun used in all the above positions was the Lewis gas operated gun as it was more readily available than any other type and had the advantage for air work of being lighter.

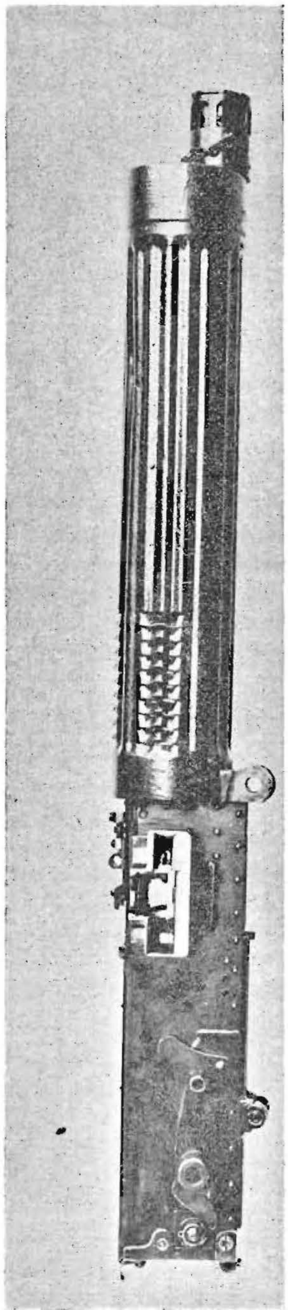


Lewis Gun on Scarff Ring

In the autumn of 1915 the Germans sprang the biggest technical surprise of the war by producing a Fokker fitted with a machine gun synchronised to fire through the plane of rotation of the airscrew. This device enabled them to use reliable belt-fed guns installed in the cockpit and having a large ammunition supply. The sighting was amplified as the gun was mounted along the line of flight of the aircraft. It was in consequence of this development that, for a



Vickers ·303-inch Mark I (Ground Gun)



Vickers ·303-inch Mark I*

considerable period, the R.F.C. lost air superiority in France. As a countermeasure to this, we tried fitting deflector plates to the airscrew blades and firing through the plane of rotation. These plates afforded a certain amount of protection if the blades were hit. This temporary measure met the emergency until a synchronising gear could be developed. The earliest British design of interrupter gear was the Scarff-Dibovsky mechanical linkage gear which was not very satisfactory and was soon superseded by the Constantinesco hydraulic gear which remained in first line aircraft up to 1936.

At the end of the First World War, the majority of single-seater aircraft were fitted with one and sometimes two, fixed Vickers guns, and some of them had, in addition, a Lewis gun fitted to the upper rear spar and movable over a limited field so that the pilot could shoot from underneath his target. Two-seater aircraft were usually fitted with one fixed forward-firing gun, and one, sometimes two, rearward firing Lewis guns operated by the observer. This general arrangement of armament continued in use until 1935–36, when wing guns were first introduced.

Development 1919 to 1935

Large and small calibre guns

Controversy on the question of aircraft gun armament was rife at the end of the First World War. Several views were held by the Air Staff varying from the adoption of a semi-automatic gun firing a heavy high explosive shell, to the ultra-light machine gun of ·28-inch calibre. One school of thought advocated the adoption of heavy guns of 37-mm. or greater calibre, firing high explosive shells. The second school held the view that the system of fighting employed at that time should be retained, but made more effective by the adoption of a larger gun such as the ·5-inch. Some sections of the Air Staff went to the other extreme, recommending the adoption of the ·28-inch ultra-light high-speed machine gun in order that more ammunition might be carried to allow for the rapid expenditure which was expected of a gun firing from 1,500 to 2,000 rounds per minute.

Vickers ·5-inch gun

With the advent of armoured enemy aircraft towards the end of the First World War, development of a ·5-inch machine gun to replace the ·303-inch Vickers as a fixed gun was put in hand. Before any real headway could be made, however, the Armistice had been signed and the development of the gun continued in the years immediately following, but at a more leisurely pace. The gun produced was an enlarged version of the ·303-inch Vickers and had a rate of fire between 600 and 700 rounds per minute,[1] the muzzle velocity being 2,650 feet per second as compared with 2,450 feet per second for the ·303-inch. Some doubt was expressed as to its suitability for use as a synchronised gun as it was thought that an unsynchronised shot, which occasionally occurred due to defects either in the synchronising gear, gun or ammunition, would completely shatter the propeller should it strike it. It was ascertained, from special experiments, that the bullet would penetrate wooden propellers without endangering the immediate safety of the aircraft.

[1] Seventh Report of the Director of Research, October 1919.

It was proposed to install these guns in the 'Nightjar' (a single seater fighter in production at that time) and a contract was placed with Vickers for 12 guns in order to conduct service trials. Considerable difficulty was experienced in firing the guns in synchronisation with the propeller, and as aircraft were being built to take this calibre gun, it was thought advisable to have an alternative gun should the difficulties of synchronising the Vickers prove insurmountable or uneconomical.

Browning ·5-inch guns

Early in 1924 three Browning guns were purchased from the Colt Patent Firearm Company of America and acceptance trials successfully completed. Comparative trials with the Vickers and Browning were carried out during the next three years and by May 1927 the Air Staff were still reluctant to make a decision as neither gun had proved superior in all respects to the other. The Browning was more powerful than the Vickers, firing a bullet 30 per cent. heavier at the same velocity, but this was counter-balanced by the gun weighing more and being 7 inches longer.

Meanwhile experiments were commenced at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) to determine the destructive properties of the ·5-inch ammunition as compared with the ·303-inch. The guns were fired at airframe and engine components and also at running engines and it was found that the ·5-inch bullet caused little more damage than the ·303, and was not as destructive as the smaller calibre weight for weight.[1]

By May 1928, the Air Staff were satisfied that they had investigated, as fully as possible, the comparative merits of the Vickers and Browning guns and also ·5-inch ammunition against the ·303-inch calibre. It was decided that nothing would be gained by the immediate adoption of ·5-inch guns and all development work was suspended. As a result, in 1928, aircraft were still equipped with ground guns, hastily adapted for air use in the early day of the First World War. C.A.S. urged the development of a good gun or guns of ·303-inch calibre with which to replace the Lewis and Vickers.

It is of interest to note that whilst the adoption of the R.A.F. of ·5-inch guns for use in aircraft had been under consideration, the American services had also been comparing the efficiency of the ·5-inch and ·30-inch (the American rifle calibre) machine guns. The conclusions reached by the U.S.A. Services were similar to our own, but they decided nevertheless, to install one ·5-inch and one ·30-inch gun in their aircraft.

·8-inch calibre guns

One of the first attempts to develop a machine gun of greater size than the ·303-inch was made in 1923.[2] At the request of the Deputy Director of Research (Armament) (D.D.R. (Arm.)) who maintained that something larger than a ·5-inch gun was required by the observer,[3] the Ordnance Committee instigated experiments to determine the effectiveness of ammunition fired from a ·8-inch calibre gun. As a result of their research, it was considered that the

[1] A.M. File S. 26802.

[2] Fifty-third Report of the Director of Research, July 1923.

[3] ·5-inch guns were under consideration for adoption as 'fixed' guns at that time.

effect of ball or armour piercing ammunition of this calibre was not commensurate with the increase in size and weight, and an explosive bullet would do little more than indicate the point of impact.

Later, further tests to establish the effect of large calibre bullets against aircraft components were held. In these tests a ·9-inch gun was used; that being the only gun of suitable calibre readily available. Not satisfied with the results of these trials, a further attempt was made, this time a ·8-inch aiming rifle being used, to fire against numerous targets which included aircraft components, fuzed bombs and pyrotechnics. These experiments were carried out between 1923 and 1926 and little appears to have been learnt from the results, and the idea of using guns of this calibre was finally abandoned without any attempt having been made to design an aircraft gun of this size.

·5-inch observer's gun

From the trials of the Vickers and Browning ·5-inch guns in 1924, it was hoped there would emerge one gun suitable for adoption as either a pilot's or observer's weapon, thus simplifying the problem of supply. It became apparent at an early stage of the trials, that neither gun would prove acceptable as a 'free' gun, irrespective of the final results. Both guns were belt fed, and the difficulties of mounting this type of gun as a hand-held weapon were, at that time, insurmountable.

Some time elapsed before ·5-inch calibre guns were again considered as an observer's weapon. In 1928, two ·5-inch guns had been completed and supplied by Messrs. B.S.A., against a contract placed in 1925 for an observer's gun. Their mechanisms were identical, being recoil operated and fed from a magazine of the Lewis type containing 37 rounds. They differed in the method of handling; two systems being provided in order to determine, by comparative tests, which was more convenient from the user's point of view.

The acceptance trials were not successful; stoppages due to poor extraction and ejection and also others attributed to the magazine, occurring with frequent repetition. Trials in the air were, however, carried out at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) to determine which system of handling would prove superior, as it was hoped to obtain data on this matter which might assist in the design of future weapons. The Chief of the Air Staff decided in May 1928 that nothing would be gained by the introduction into the R.A.F. of ·5-inch guns unless the use of armour in aircraft forced a revision of policy. As a result, all work on ·5-inch weapons was suspended and work concentrated on development of ·303-inch guns. At the same time the Chief of the Air Staff strongly criticised the gun armament of aircraft, pointing out to the Air Member for Supply and Research (A.M.R.S.R.), that whilst aircraft design had progressed rapidly, their gun armament had stagnated, leaving the R.A.F. still equipped with the wartime Vickers and Lewis guns. The cause of the stagnation was, however, primarily due to lack of money for development of armament and the inadequate staff of Assistant Director of Armament Research and Development (A.D.R.D.Arm.).

Small-calibre machine guns

Serious consideration was given to the adoption of calibre less than ·303-inch in 1927, after similar tentative recommendations had been made in earlier years without the matter being pursued to any conclusion. The requirement arose out of the need for a weapon of considerably less weight than the ·303 Vickers, for installation in a multi-gun single seater fighter which was contemplated. As a result of a meeting at the Air Ministry in October 1927, it was decided to put in hand the design of a ·28-inch calibre gun, bullet and cartridge, having a muzzle velocity as high as possible preferably 2,500 to 3,000 feet per second.

Preliminary designs of the ammunition were prepared and design of the gun commenced, but by February 1928, the Air Staff ruled that all work on this calibre should be suspended pending the results of other gun trials in progress at that time. Up to then it had been thought impossible to develop a gun of ·303-inch calibre, or larger, to fire at a speed of more than 1,000 rounds per minute, and that the high speed and reliability required of an aircraft gun was only obtainable by weapons of smaller calibre. Further considerations which influenced unfavourably the adoption of small calibre guns was the difficulty of making incendiary, tracer and explosive bullets in the smaller size, and the vast expenditure and difficulty involved in producing, in the large quantities required, ammunition other than the standard ·303-inch Service cartridge. The adoption of a ·28-inch gun was not considered after 1928, and such preliminary work as had already begun on its design was abandoned.

Adams and Willmott gun

This gun derived its name from its co-designers, Captain Adams of the department of the Assistant Director of Research and Development (Armament) A.D.R.D. (Arm.), and Mr. Willmott of the Royal Aircraft Establishment (R.A.E.). The initial design work did not commence until 1931, and the production of two guns, which B.S.A. manufactured for trials, was delayed by the more urgent work of developing the Browning gun.

The A. & W. gun was light and easy to handle, and allowed the gunner plenty of room in the gun ring as it was designed to give minimum inboard projection. The gun entered the trials which were being held to find a replacement for the Lewis gun,[1] during the final stages, and having regard to the short time it had been under development, achieved remarkable success. It was rejected from the trials on account of difficulties experienced with the magazine feed which required further development before the gun could be considered suitable for inclusion in the trials. The replacement of the Lewis gun was, by that time, a matter of extreme urgency and a decision in favour of one of the guns on trial had to be reached not later than the last day of 1935, by which time the A. & W. gun had not been eliminated from the trials. The gun was in the early stages of development and facilities for its rapid improvement were not available. It was decided that work on the gun should be abandoned.

Twin and double barrelled free guns

As an alternative to adopting a single barrelled high speed gun firing from 1,000 to 2,000 rounds per minute, attempts were made to develop a twin coupled or double barrelled gun with which to arm the observer. During the First World War a twin Lewis had been designed and used but the coupling device was large and cumbersome.

[1] Other makes of gun in the trial were Lahti, Darne, Vickers G.O., Madsen.

Although often suggested as an alternative to the orthodox single barrelled gun, during the post war years, it was not until 1930 that any real attempt was made to design an observer's gun with two barrels. The advantages of using this type of weapon were :—

(*a*) Greater volume of fire, and therefore increased bullet density.

(*b*) In the event of one gun stopping, the observer could continue combat (with decreased efficiency) by maintaining fire with the remaining gun.

(*c*) Whilst still maintaining a high combined rate of fire, the speed of each gun could be controlled within limits to ensure long life of component parts, and an extended life of the barrel, which in high speed single barrel guns deteriorated rapidly due to overheating.

The disadvantages were :—

(*a*) Increased weight.

(*b*) Difficulty of synchronising both guns to fire in phase with each other. owing to the varying rate of burning of the propellent ; and the impracticability of making two guns to operate at exactly the same rate. Therefore one gun would invariably cease to fire with the magazine empty, in advance of the other.

(*c*) Difficulty to manœuvre the guns rapidly when changing aim, owing to increased mass and consequently increased resistance in the slip stream.

With the need to find an efficient replacement for the Lewis, twin and double barrelled guns were considered on parallel with single barrelled guns.

B.S.A. double barrelled gun

In 1930 Messrs. B.S.A. were asked to design a double barrelled machine gun of ·303-inch calibre with a combined rate of fire of 1,500 rounds per minute. The gun was to be light and compact, with an independent magazine for each barrel ; the magazine to contain approximately 100 rounds. By December 1931 initial trials of the gun had been completed, but were disappointing ; breakages occurred frequently and the gun's general performance was poor. Despite these early set backs, air trials were conducted throughout 1932, but, as was feared. the gun's weight and resistance to the slip stream made it unwieldy to handle. Also, the mechanism, despite modification, was still unreliable, and the gun was rejected on account of these failings which were considered to be inherent in the design of the gun.

The Assistant Director of Research and Development (Armament) (A.D.R.D. Arm.) upon whose recommendation the gun had been designed, was reluctant to abandon completely all hope of developing such a gun as he was firm in his belief that it could be designed to operate better than any single barrelled gun under review at that time, and so, in May 1933, a further contract was placed with Messrs. B.S.A., this time for a gun with mechanisms identical to the Lewis gun. After several unsuccessful trials of the new type in 1935, it was decided to abandon the design and development of double barrelled guns entirely as it was apparent that the disadvantages outweighed the advantages to be gained by adopting this type of weapon. Furthermore, there was every hope of a single barrelled gun emerging from those under test, with a rate of fire comparable with that of the B.S.A. double barrelled gun.

CHAPTER 2

VICKERS G.O. GUN

Endurance trials of guns to replace the Lewis as a free gun for rear defence of bomber aircraft were held in 1930. One of the guns was a Vickers Berthier which had been designed in 1908 by a Frenchman, Lieutenant Berthier, and was in use in the Indian Army as an infantry weapon. The ground trials, carried out at Enfield, were completed by the middle of 1931, and showed that the Vickers Berthier was light and easy to handle, but the rate of fire was rather slow, furthermore components were liable to fracture. After air firing trials, the gun was returned to Messrs. Vickers for modification to increase the rate of fire and improve reliability. These were only partially successful, the rate of fire had been increased, but the gun was still unreliable.[1]

At the end of 1931, the Air Ministry issued a general specification for aircraft machine guns, and Messrs. Vickers decided to re-design the gun to improve its reliability and conform with the Air Ministry specification. The new gun, known as the Vickers ' K ', was ready for official trials by the middle of 1935. It was similar in general principle to the Berthier, but was of more robust construction, and in particular the speed had been increased to the 1,000 rounds per minute required by the specification.

Comparative trials with other types of free gun to replace the Lewis,[2] were arranged in September 1935. As a result of ground and air firing trials it was considered that only two—the Darne and the Vickers ' K '—were worth serious consideration.[3] Further tests at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) showed that the Darne gun compared unfavourably with the Vickers, the main disadvantages being its lack of manœuvreability at operational speeds, its inaccuracy due to its extremely fierce action (ejected cases were thrown 40 feet) and large number of small components liable to fracture. The Vickers ' K ' was accepted as a replacement for the Lewis gun in February 1936, an experimental order for 200 being placed for Service trials.

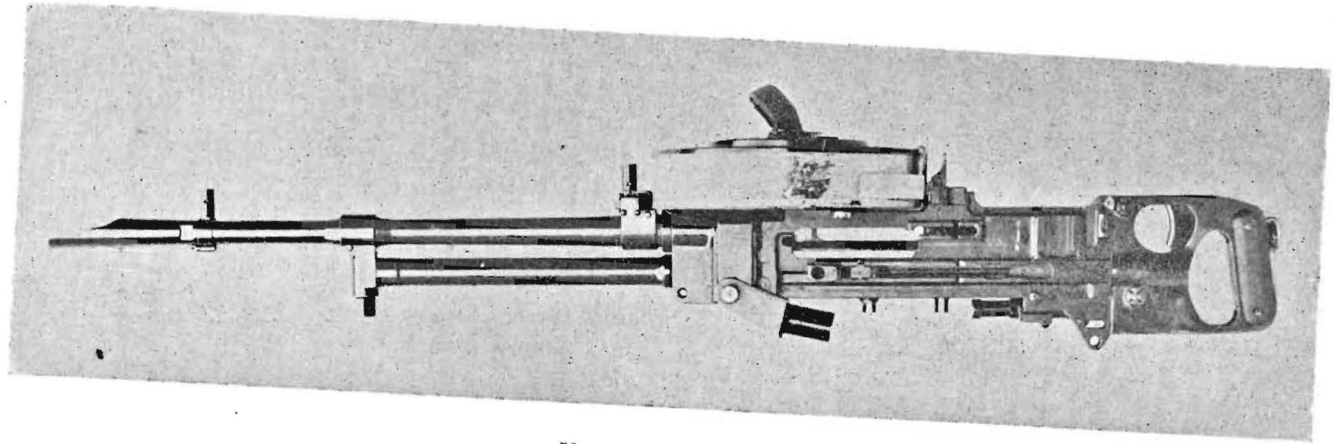
The main troubles with the Vickers ' K ' were with the spring-loaded magazine and extractors, and although the first 200 guns were to be to the original design, Messrs. Vickers undertook to improve both the magazine and extractors on the production models. During 1936 Messrs. Vickers completely re-designed the magazine, increasing its capacity from 60 to 100 rounds, and at the same time simplifying methods of loading it. The extractor and spring were also re-designed, but this meant an alteration to the breech block, with the result that the part was not interchangeable with the production models.

The Vickers G.O. was also to be used in turrets which were designed for single guns, and consideration was given to using the gun in the wing installation of fighter aircraft. The Vickers had several advantages over the Browning

[1] A.M. File S. 29619 Encl. 66A.

[2] Other guns were the Hotchkiss, Lahti, Darne and A. & W. (Adams & Willmott).

[3] A.M. File S. 29619 Encl. 152A.



Vickers G.O. Gun

it had fewer parts and was easier to strip and service. Messrs. Vickers designed and manufactured a magazine to hold 300 rounds of ammunition for use with fixed installations, and were asked to investigate one to hold 1,000 rounds. Air firing trials, carried out early in 1937,[1] were very successful—the Vickers G.O. fitted with the 300-round magazine was considered suitable for wing installations, and compared favourably with the Browning gun for reliability. Trials with a 600-round magazine during the autumn of 1938 were not so successful, stoppages occurring due to misfeeds. It was found that the magazine spring did not feed the ammunition fast enough for the gun and it was decided that no further work should be carried out.

During 1938, a fair amount of experience was obtained in the use of the gun. It functioned well on the whole and was a great improvement over the Lewis with regard to reliability and maintenance. The 60-round magazine was, however, liable to give trouble if incorrectly loaded; a fault which would remedy itself as the armourers gained more experience. Trouble was also experienced due to 'caps out'; the empty case was ejected so violently that the cap could separate from the case and was liable to fall into the mechanism of the gun and cause stoppages. This was rectified by re-design of the ejector.

Breakage of small components occurred too frequently to be acceptable in the Service and towards the end of 1938 endurance trials were carried out to assess frequency of occurrence. Messrs. Vickers investigated the possibility of modifying the components affected, but the position was now complicated by the fact that an increasing number of guns were being issued to the Service, and any modification undertaken would not have to affect the changeability of the item. This made the re-design of the extractor spring extremely difficult, but early in 1939 Messrs. Vickers had produced satisfactory modifications.

Trials of the modified parts were carried out on the range of the Chief Inspector of Small Arms (C.I.S.A.) at Enfield. The results were very satisfactory and the weapon was considered suitable for Service use. The average life of components was such that it was decided that no spare parts for the Vickers G.O. need be carried in the air.[2] It had originally been intended to leave a number of Lewis guns in the Service, but in view of the marked superiority of the new gun and the imminence of war, the Air Staff decided that all Lewis guns were to be replaced by Vickers G.O. guns. Messrs. Vickers were at that time designing a ground gun for defence of aerodromes, but to meet the large increase in the number of guns required by this decision, production of the ground gun ceased, and all capacity was concentrated on aircraft guns.

In order to increase the fire power for bomber defence a twin version of the Vickers G.O. gun was considered. This twin gun, which was ready towards the end of 1938, consisted of two G.O. guns mounted on their sides with the feed openings outwards and ejection openings downwards. The mounting yoke was replaced by a fitting which connected the two guns together, and the back blocks were replaced by a common back block connecting the two guns at the rear, and having a single gear mechanism. In the left-hand gun the body and breech block were special parts and not interchangeable with the standard components. The first trials with the gun were not very successful; it gave

[1] A.M. File S. 39157 Encl. 36A.

[2] It had been the practice to carry a spare breech block and piston in the air when armed with Lewis guns.

frequent ' caps out ', in spite of the modified ejector, and suffered a number of breakages of minor components. After firing a considerable number of rounds, the gun was returned to Messrs. Vickers. Upon examination and fuller range tests, it was found that although originally the gun fired at 1,000 rounds per minute, during the trials the speed had worked up to over 1,200 rounds per minute, and it was this high speed that was causing ' caps out ' and the breakage of components. The gun was re-built by Vickers and a further trial carried out on the Army range at Hythe. The gas recoil system had been adjusted to keep the speed below 1,000 rounds per minute, and the gun fired 20,000 rounds without further trouble. At the end of this trial the bodies and back block had fired over 40,000 rounds and one body was still serviceable. The Air Staff were notified that the new Vickers G.O. gun was considered suitable for use in the Service, but there were considerable delays in deciding whether the twin gun should be adopted.

Before a decision had been given, Bomber Command asked as a result of early operations, for two guns to be mounted on the rear cockpits of Hampden aircraft in place of the single gun. As, however, the production of the twin gun involved special tooling up, and consequent serious delays, it was decided, in view of the production position, to abandon further work on the twin gun.

As the war progressed, the aircraft fitted with Vickers G.O. guns were gradually withdrawn from operational use, and replaced by aircraft equipped with Browning gun turrets. By 1943, the Vickers G.O. gun was virtually obsolete in the Royal Air Force, although it continued to be issued in the Fleet Air Arm until the end of the war. A large number of guns rendered surplus to requirements were issued to the Army and Navy for ground use, mainly for defence against low flying aircraft. They were particularly popular with the Commandos in Libya, who preferred them to the Bren gun because of their greater speed and greater reliability under desert conditions. In an effort to prolong the service life of the gun, Messrs. Vickers designed a belt feed attachment, and although some firing trials were carried out, this project did not get beyond the experimental stage.

CHAPTER 3

BROWNING GUN

The ·303-inch Browning gun was one of the most important guns used by the R.A.F. during the Second World War. It was the standard fighter aircraft armament until the middle of 1941, and was the gun with which the Battle of Britain was won. It remained the main bomber defence armament throughout the war and there were very few operational aircraft which did not carry a Browning gun. In addition it was by far the most reliable gun in the Service and was produced in greater quantities than any other.

Early history

The Browning gun has had a long history, being designed originally in 1900 as an infantry weapon. In July 1918 a ·300-inch calibre gun, adapted for air use and fitted with interrupter gear, was received from the United States, and successful trials were carried out with the gun fitted to a Bristol Fighter aircraft. In the years immediately following the First World War, the Air Ministry was mainly interested in developing a ·5-inch calibre gun as a replacement for the ·303-inch Vickers in fighter aircraft, and little work was done on rifle calibre (·303-inch) guns. In October 1923, however, representatives of the Air Ministry witnessed a trial of an improved version of the original ·300-inch Browning, on the ranges of the Chief Inspector of Small Arms (C.I.S.A.) at Enfield, and were favourably impressed with its performance.

In view of the interest the Air Ministry had shown in the gun, Messrs. Armstrong Whitworth had acquired the British manufacturing rights for the Browning gun, and representatives of Armstrong Whitworth's visited the American firm of Colt Firearms in April 1924 to obtain drawings, manufacturing data and sample guns of both the ·5-inch and ·300-inch calibre guns.[1] During 1925, Messrs. Armstrong Whitworth converted two of the American made ·300-inch guns to take the British ·303-inch ammunition and trials were carried out at Enfield. The Director of Equipment, Air Ministry, asked, in July, whether there was any intention of adopting the ·303-inch Browning, but was told that no decision was expected for some months.

An order for six ·303-inch Browning guns was placed with Messrs. Armstrong Whitworth in March 1926; the guns were to include certain modifications which had been found necessary on the American made guns; in particular, trouble had been experienced with the trigger motor fitted to these guns. The first of the new guns was delivered in March 1927; in the meantime a new trigger motor had been designed at the Royal Aircraft Establishment (R.A.E.) and a contract for the manufacture of six placed with Messrs. Armstrong Whitworth.

Various trials were carried out by the Chief Inspector of Small Arms (C.I.S.A.) on the first gun and a number of small modifications to components were carried out; by April 1928 the gun had fired 2,530 rounds.[2] The delivery of

[1] A.M. File 458957/23. [2] A.M. File 644625/25.

the other five guns was delayed, partly because it was necessary to embody the modifications found necessary in the trials of the first gun; also the amalgamation of the firms of Armstrong and Vickers during 1927–28 may have affected production. In the meantime, during 1928, the Air Staff decided that the ·5-inch gun had not sufficient advantage over the ·303-inch gun to warrant its adoption, and development work on the larger gun ceased. The guns were delivered in the middle of 1929, and arrangements were made for two of them to be mounted in a Siskin aircraft for air firing trials. There were, however, further delays in getting the guns installed, and it was June 1931 before the trials took place. These trials were a complete success, one gun fired 14,400 rounds with only three stoppages—two of which were due to broken links; and the other fired 5,200 without any stoppages; maintenance was very favourably reported on.[1]

By that time the Colt Company had completely re-designed the 'rifle calibre' gun to make it more suitable for use in aircraft. A demonstration of the new gun, known as the ·30 Calibre M.2 was witnessed by Air Ministry representatives at Messrs. Vickers Armstrong works at Crayford in January 1931, after which it was recommended that four guns should be purchased, and that all future trials should be done with that type.

Messrs. Vickers Armstrong had not retained the manufacturing licence for Browning guns which had previously been held by Armstrong Whitworths, but they still acted as agents for Colt Patent Firearms Company. An order for four guns was therefore placed with Vickers Armstrong, the guns being delivered in the middle of 1932. There were two types; a fixed gun with a short barrel casing intended for fighter aircraft; and a free gun for observers' use which had a long barrel casing and muzzle attachment; the latter gun was some 300 rounds per minute faster. The order for the four guns comprised two of each type, but the drawback of belt feed is fundamental to a hand held gun and it was decided that it was not suitable for an observer's gun. It was found, however, that the observer's gun was far more accurate than the pilot's owing to its long barrel and casing, and, as it was also the faster, it was decided to use that type for fixed gun fighter installation, and no further work was done on the short-cased pilot's gun.

The two long barrel type guns were, after preliminary ground trials, installed as fixed guns in a Hawker Fury aircraft, and air trials were carried out at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) during 1933 and early 1934. The synchronising gear trigger motor gave a lot of trouble during these trials and had to be considerably modified; a certain amount of trouble was also experienced with fouling in the muzzle attachment.[2] These trials, completed in June 1934, were part of a series carried out to select a gun as a replacement for the ·303-inch Mark V Vickers gun. The results showed that the Browning gun, although needing further development, was definitely superior to others on trial.[3] Accordingly on 22 June 1934, it was recommended that the Browning gun should be considered as the best replacement available

[1] A.M. File S.28307. [2] A.M. File 82712/31.

[3] Two other types on trial were the Darne and Vickers Central Action.

for the Mark V Vickers. The advantages of the Browning over the Vickers in service were :—

(*a*) Increased rate of fire (from 800 to 1,000 rounds per minute).

(*b*) Improved reliability.

(*c*) Improved freedom from breakages.

(*d*) Reduction in total weight of 5 lb.

(*e*) Reduced pitch of ammunition belt.

It was also pointed out that as Messrs. Vickers no longer held the manufacturing licence, the Air Ministry would be free to choose any firm they wished to manufacture the guns in this country. Early in July 1934, the Air Member for Supply and Research (A.M.S.R.) approved the purchase of sufficient ·303-inch Browning guns to equip two squadrons for extended service trials[1] and after some further correspondence between interested branches, it was finally agreed, in October 1934, that sixty guns should be ordered direct from the Colt Patent Firearms Company.

The question of manufacturing the Browning gun was discussed with Messrs. Vickers Armstrong, but they did not have sufficient manufacturing capacity to produce the gun in the numbers required. Moreover the gun obviously required further development which Messrs. Vickers were reluctant to undertake because of the work they had in hand in connection with the development of the Vickers G.O. gun. As much of the development work had been done by Air Ministry staff, it was finally agreed that the Air Ministry would acquire the manufacturing right of the Browning gun for the British Empire, and be responsible for its development. A small quantity of guns were to be manufactured by Messrs. Vickers, but the bulk of the Air Ministry's future requirements would be met by Messrs. B.S.A.

As a result of the trials with the first ·300-inch calibre 42 pattern guns, the following alterations had been found necessary :—

(*a*) Modification to the firing pin/sear assembly to strengthen the sear spring, as the original would not stand up to operation by the trigger motor.

(*b*) Modification to the barrel extension to improve clearance of the ejector.

(*c*) Addition of a flash eliminator.

(*d*) Addition of a bracket to the bottom plate to take a loading mechanism similar to that used on the Vickers gun.

All the alterations were carried out on one of the original pattern guns and arrangements were made for them to be incorporated in the sixty guns which were on order from Colt's Patent Firearms Co. The modified gun was fitted to a Gauntlet aircraft but air firing trials carried out early in 1935, ended with a bad accident to the gun. Part of the trial consisted of firing 100 rounds in a dive, repeated several times in quick succession. During one of these there was a loud explosion in the gun which immediately stopped and when examined was found to be completely wrecked. In common with the Vickers, and most other recoil operated guns, the Browning ceased fire with a round in the chamber, and the firing pin cocked. After a 100 round burst the barrel was so hot that

[1] A.M. File S. 29619.

the cartridge then remaining in the chamber had been heated to such a degree that the propellent had ignited. As bursts of that length were a definite requirement by Fighter Command, it was decided to modify the gun so that on ceasing fire the breech block remained at the rear of the gun with the chamber empty. This meant designing a sear in the breech block at the rear of the gun and firing the gun by releasing this sear. This was a major modification ; the design was carried out by the Research and Development (Armament) (R.D. Arm.) branch of the Air Ministry, and an experimental rear sear was made by Messrs. B.S.A. who fitted it to the last of the original 1930 pattern guns. It may be questioned why the Colt Company had not foreseen this difficulty ; the main reason was that the nitro-cellulose propellent used in the United States Army was not so liable to ignition when heated as the cordite used by the British Forces ; and even when nitro-cellulose ignites it does not give rise to such high pressures as cordite.

Messrs. B.S.A. were now tooling up for production, using the drawings supplied by the Colt Company, and a closer investigation was made into the design of the Browning gun than had previously been necessary. During this detailed examination, several other defects were brought to light which resulted in the following modifications being introduced :—

(*a*) Introduction of rear sear, which entailed a new lock frame and modification to the bottom plate and side plates.

(*b*) Modification to the feed lever to give equal length of feed for right- and left-hand feed.

(*c*) Modification to the retaining pawl and filling pieces.

(*d*) Re-design of cartridge stop to suit British incendiary ammunition.

(*e*) Taper barrel casing to increase its rigidity.

(*f*) Chromium plating of muzzle end of barrel to reduce accumulation of fouling.

All but the first of these alterations were to be introduced by Colt's on the first sixty guns on order, but because of the large amount of work included in the first alteration it was agreed that this would be incorporated by Messrs. B.S.A. The new lock frames and rear sears for these guns had already been manufactured by B.S.A., but when they attempted to carry out the modifications, it was found that the new parts would not fit the guns.

A check of the guns against the American drawings held by B.S.A. revealed a number of serious discrepancies. Moreover, whilst designing the necessary jigs and tools for production, a large number of errors were found in the drawings. In consequence a visit was made to Colt's Works by representatives of the Air Ministry and Messrs. B.S.A. This visit revealed that three sets of drawings existed for the Browning gun ; the manufacturing drawings to which jigs and tools were made ; inspection drawings to which the finished product had to conform ; and the official U.S. Ordnance drawings for guns supplied to the U.S. Army. The drawings which Colt's had supplied to the Air Ministry were the inspection drawings, and it was found that the difference between those for manufacture and inspection was due in many cases to the former being to closer limits and also to a fair amount of hand fitting of components prior to final assembly.

The design of jigs and tools at Messrs. B.S.A. was in an advanced state and, owing to the large number of guns involved, production was being planned to reduce hand fitting to a minimum. In consequence of this, and also because major alterations to the drawings would be necessary to incorporate the various modifications required, it was decided that the Air Ministry should make their own drawings of the gun based on the work so far completed at Messrs. B.S.A.

It was decided to form a separate drawing office as part of the Research and Development (Armament) (R.D. Arm.) branch, to undertake the preparation of the Browning gun drawings. This office was located at the Royal Small Arms Factory at Enfield and commenced work in the summer of 1936. During the preparations of these drawings further modifications were carried out to the gun both to improve its performance and facilitate production. These modifications consisted of :—

(*a*) New bottom plate incorporating the mounting for the loading mechanism which had been a separate bracket on the first guns.

(*b*) New back block, made by forging instead of being built up as in the original gun. This modification was intended to strengthen the gun.

(*c*) Modification to the external shape of the barrel to assist production.

(*d*) Re-design of the muzzle attachment and flash eliminator, mainly to provide a more efficient flash eliminator.

Continual trouble with the feed on the early production guns led to a complete re-design of that mechanism, and included a new feed lever, feed pawl and feed slide. In addition, a number of small alterations were made to various other components, mainly by adjusting limits and dimensions to avoid interference and ensure interchangeability. In addition to preparing drawings for the actual gun, the R.D. Arm. drawing office produced designs for several items of ancilliary equipment required for the gun. The first was a loading mechanism for loading cockpit guns and was similar in design to that already in use on the Vickers gun. For wing mounted guns the loading mechanism was not used ; the guns being loaded on the ground by the armourers who had a loading lever as part of their equipment.

When the rear sear was fitted it was necessary to arrange for the firing pin sear to be automatically released when the breech block reached its forward position. This was done by fitting a plunger to the side of the gun which released the sear as the breech block reached its forward position. This plunger was made retractable ; in the retracted position the breech block would go forward without firing the gun ; it therefore acted also as a safety device, and although originally fitted to operate the firing sear, it was known as the 'Fire and Safe' mechanism. This was not fitted to synchronised guns, its place being taken by the trigger motor. The rear sear was released by a pneumatic firing unit when fitted to an aircraft and a hand firing unit was designed for use when testing the gun on the ground.

The first British made Browning guns were delivered in March 1936, but it was not until the end of that year that any large quantities were being produced. To provide guns for new aircraft a further order for 600, and later for another 1,000 guns was placed with the Colt Company, so in all 1,660 American made Browning guns were purchased. By the time the gun was reaching the service in large quantities, all major defects had been eliminated by the various modifications that had been made. Trouble was experienced due to poor servicing, but this improved as the armourers gained experience with the new gun; in particular, 'breeching-up' was liable to cause trouble. Unlike other guns previously used in the Service, it was possible with the Browning gun to adjust the fore and aft position of the barrel breech face relative to the breech block. If the barrel was too far back, the breech would not lock; whereas if it was too far forward, the cartridge case was not supported by the wall of the chamber and the pressure of the gases would cause the case to expand. This could cause the case to split and sometimes the neck of the cartridge case was left in the chamber causing a stoppage known as a 'separated case.' The usual fault was to adjust the barrel too far forward and stoppages due to separated cases would occur.

In Service use it was found that occasionally the firing pin would slip off the firing pin sear and give rise to stray shots when the guns were controlled by synchronising gear, and to prevent this the sear barrels were undercut. The introduction of this modification raised a question that became one of the main considerations when a modification was contemplated. Hitherto a modification had only affected the manufacture of the gun, but there were now so many guns in the Service that the question of how the modification was to be carried out on the guns already issued, was often more important than how it affected production. From then on, no modification could be made if it seriously affected interchangeability of existing weapons, or could not be applied to existing guns.

During 1938, a series of endurance trials were carried out both on the ground and in the air, mainly for the purpose of assessing the maintenance requirements of new guns. The trigger motor was still not satisfactory; in particular, the trip lever had a very short life; but as synchronising gear was obsolescent and would not be fitted to the new fighters, it was decided not to re-design the unit. The air trials showed that the majority of stoppages were due to poor maintenance and as a result of these trials no further modifications to the gun were considered necessary.

At that time Fighter Command stated a requirement for the Browning gun to be capable of firing bursts of 300 rounds duration. This was found to be impossible on existing guns as after firing 200 to 250 rounds continuously, so much fouling accumulated in the muzzle attachment that the barrel seized and stopped the gun. Even in normal use the muzzle attachment had to be cleaned at frequent intervals and the removal of fouling from it was one of the most difficult maintenance operations on the gun.

It was decided therefore, to re-design the muzzle attachment with a view to reducing the accumulation of fouling. After a number of experiments carried out at Messrs. B.S.A.'s works, a successful design was produced early in 1939, and samples were submitted to Fighter Command and the Aircraft and Armament Experimental Establishment (A. & A.E.E.) for air trials. These trials were a complete success; not only did the new attachment permit bursts of 300 rounds to be fired, but it was possible to fire 6,000 rounds before it had to be cleared. This meant that even if 300 round bursts were not normally used, the maintenance of the gun would be greatly simplified, as the cleaning of the muzzle attachment would have to be carried out at less frequent intervals. The new attachment was approved for service use as a retrospective modification in May 1939. At that time B.S.A. were producing 500 guns per week and Vickers 100 per week; B.S.A. also planned a weekly production of 1,000 muzzle attachments by the following July. The guns made by Vickers were to be fitted with the muzzle attachments made by B.S.A., thus leaving a weekly output of 400 attachments for retrospective modification of existing guns. It was estimated that between 15,000 and 20,000 guns would have been issued to the Service by July; hence it would take approximately ten months before all guns in the Service were modified. This was the last major modification carried out to the Browning which became a thoroughly reliable service weapon.

Development 1939–45

The gun at this stage was known as the Mark II*, and the mark number was not altered again. From then on the Browning gun ceased to be a design problem and the majority of other minor alterations were to facilitate production. During the winter of 1939–40 aircraft were operating under more severe weather conditions than would be usual in peace-time and a considerable amount of trouble was experienced in certain aircraft due to guns failing to function at low temperatures. On most of the fighter aircraft, in particular the Spitfire and Hurricane, this had been foreseen and the gun compartments were lagged and heated from the engine exhaust. In other aircraft, particularly where guns were mounted in turrets, no provision for gun heating was made.

These gun stoppages were due to two main causes. First, congealing of the oil lubricant, and secondly the formation of ice on the gun mechanism. The former was remedied by using a mixture of anti-freeze oil and paraffin for lubrication which, although successful in preventing the guns from freezing up, had very bad anti-rust properties which increased the difficulties of maintenance. No satisfactory cure for ice formation was found; attempts were made to heat turret guns electrically, but the amount of current required to do this effectively was prohibitive.

By the middle of 1941 the production of Browning guns had reached 2,000 per week, at which figure it will be appreciated that quite small changes in design could effect considerable saving in man and machine hours. In consequence Messrs. B.S.A. proposed a number of modifications, mainly directed to reducing the machine hours on the gun and reduce wear on the machine cutters. The majority of these were of a minor nature, the most important being the deletion of the trunnions on the trunnion block, as these were not used on any existing installation, and deletion of hardening on the barrel extension. After due consideration, which included trials of unhardened extensions, all these modifications were agreed and the manufacturing drawings were amended. The question of right- and left-hand feed was also raised by Messrs. B.S.A., it being pointed out that when once issued to a squadron, the direction of feed was rarely changed, and if guns were made for left- and right-hand feed only much saving in time of production would result. There were no technical objections to this, but it was strongly opposed by the Director of Equipment, who considered that it would lead to confusion in equipment depots, and the matter was subsequently dropped.

In July 1941, the question of testing guns for use in aircraft fitted with synchronising gear was raised by the Armament Research and Development branch. Originally all guns had been tested at the manufacturers and this caused considerable delays in passing out guns. Only a proportion were now tested and the remainder stamped N.T.S. (not tested for synchronisation). B.S.A. had experienced no failing of guns to pass this test, and as the number of aircraft fitted with synchronising gear was rapidly diminishing it was decided to abolish it altogether, for, owing to the small number of aircraft concerned, the chance of an unsuitable gun being fitted to aircraft with interrupter gear was small.[1] By the end of 1941, the ·303-inch Browning had ceased to be the sole armament for fighters, although it was still carried in certain types of Spitfire, the Beaufighter and the Mosquito fighter. The main use for the Browning gun at that time was as a turret gun in bomber aircraft. Development of the Browning ceased by the end of 1941. The reliability achieved by the gun in the service was remarkable and unequalled by any other gun. It functioned well during the operations of 1940 which culminated in the Battle of Britain.

From the design and development point of view, production was never a serious problem, in spite of the fact that the gun was not easy to make. It consisted of a large number of small and intricate components; the breech block in particular was a machinist's nightmare. There were two reasons for the comparative absence of production problems. First, the entire production of guns was entrusted to two contractors: Messrs. B.S.A. and Messrs. Vickers Armstrong, who were both widely experienced in the manufacture of machine guns. The second reason was that the bulk of production was by Messrs. B.S.A., and from the time it was first decided to build Browning guns in this country, a very close liaison was maintained between B.S.A. and the technical staff of the Director of Armament Development (D. Arm. D.). During critical stages of the work, such as when the rear sear and new muzzle attachment were being designed, the draughtsmen preparing the design were resident at Messrs. B.S.A.'s works, and, subject to overriding technical requirements of the Service, the drawings were prepared to suit B.S.A.'s production, particularly as regards the dimensioning of datum and gauging points.

The selection of material specifications for the various gun components was also done in close co-operation with Messrs. B.S.A., which meant that many of the production troubles that arise when Government drawings are issued to a private contractor, did not occur in the case of the Browning gun.

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[1] A.M. File B. 46863/39.

CHAPTER 4

20-mm. HISPANO GUN

The Hispano 20-mm. gun was one of the two most important guns used by the Royal Air Force during the Second World War. From 1941 onwards it was the standard armament for all R.A.F. fighters, and was an important factor in maintaining the ascendancy of the Royal Air Force over the *Luftwaffe* which had been gained with the Browning gun during the summer and autumn of 1940.

Early history

Between the two world wars the Air Ministry concentrated on development of ·5-inch and ·303-inch calibre weapons which were considered adequate against contemporary aircraft. On the continent much work was done on the larger calibres by various armament firms, and early in 1930, it was generally accepted that 20 millimetre was the smallest calibre in which a satisfactory explosive projectile could be produced. The Hispano Suiza company in France had been making Oerlikon guns under licence from 1917, but later in 1933 they commenced to produce their own design of gun known as the Type 404.

Towards the end of 1935, it was recommended by the Deputy Chief of Air Staff that a ' Dewoitine 510 ' fighter which was fitted with the Hispano Moteur-cannon, should be purchased to enable trials to be carried out. About the same time the Assistant Director of Research and Development (Armament) (A.D./R.D. Arm.) and representatives of the Air Staff, attended a demonstration of the Hispano gun at the Hispano Suiza works in Paris and a similar visit was made early in 1936. After the reports of these visits had been studied, an order for six 20-mm. guns of the Type 404 design was placed with the Hispano Suiza Company. The gun was gas operated, had a positively locking breech, and was fitted with a 60-round spring driven magazine. In weight and rate of fire it proved superior to other 20-mm. guns.[1]

The first two guns were delivered early in 1937 ; the ' Dewoitine 510 ' was also delivered about that time and air trials of the gun took place at the Aircraft and Armament Experimental Establishment (A. & A.E.E.).[2] In contrast to the long series of trials which preceded the adoption of the Browning and Vickers G.O. guns, the decision to adopt the 20-mm. Hispano was made after little more than a few demonstrations at the Hispano Suiza works, and an endurance trial was delayed until it was actually in production. During 1937, a short trial was carried out by the War Office Research Department, to check the functioning of the gun and in particular to ensure that the breech block did not unlock until the projectile was clear of the barrel. The Moteur-cannon type of installation was never favoured by the Air Ministry and it was

[1] The Oerlikon and Madsen had been produced at that time.

[2] A. & A.E.E. Report 2017/Arm/482/Int. 1.

decided that the main use for the gun would be as four gun wing installation in fighters. During 1937, Messrs. Boulton Paul were working on a design for aircraft to mount four of these guns in a turret and the firm carried out a number of trials to investigate the best way of installing the gun, obtaining much valuable data.

Production of the gun was a difficult problem ; the Air Staff insisted that it must be produced in this country, and at first the firm of Aero Engines Ltd. intended to acquire the manufacturing licence for both the gun and the Hispano Suiza engine, but this did not materialise. Vickers and B.S.A. were fully engaged on the Vickers G.O. and Browning guns ; and in any case the Hispano Suiza Company were not eager to grant a licence to a rival armament firm. In the end it was agreed that they would form a subsidiary company in England especially to build the gun, and as a result the British Manufacturing and Research Company was formed and a factory was built at Grantham.[1]

As previously stated the French Government had also adopted the Hispano 20-mm. gun, and during this period were carrying out extensive trials. Representatives of the Research and Development (Armament) (R.D. Arm.) branch attended some of the trials and the close liaison which was maintained between the technical staffs of the British and French Air Ministries ensured that the results were communicated to the British Air Ministry. By the beginning of 1939, it was obvious from the French trials, and those that had been done in England, that the gun needed some further development before it could be considered as a satisfactory service weapon. It was also apparent that the production capacity of the British Manufacturing and Research Company's (B.M.A.R. Co.) factory would not be sufficient for future Air Ministry requirements, and this raised the question of future control of the design of the gun. The attitude of the Hispano Suiza Company was that having designed the gun, they wished to retain control of its subsequent development, the British Manufacturing and Research Company was intended to be a manufacturing plant only, and all development work was to be done at the Hispano factories in Paris.

In addition to the need for further development, an investigation of the French drawings of the gun by a branch of the Research and Development (Armament) of the Air Ministry showed that they were made to suit the highly specialised plant of the Hispano Suiza Paris factory and that it would be very difficult for engineering firms in this country to produce guns to the drawings should the need arise. It was decided early in 1939, that the Air Ministry would make their own drawings of the gun and that R.D.Arm.1a[2] would be responsible for its development ; a decision very unpopular with the Hispano Suiza Company.

During the course of the French trials and Boulton Paul's investigations on the installation of the gun in turrets, the following defects were found :—

(*a*) The return spring had a very short life and partly as a result of this the gun was liable to stoppages due to lightly struck caps.

[1] M.A.P. File R.A. 1341 Part 1 (formerly A.M. File S. 38135).

[2] A section of the Research and Development (Armament) branch of Air Ministry.

(*b*) The design of the extractor was poor ; the spring had a short life and the extractor was liable to slip over the rim and leave the empty cartridge in the chamber. If this happened after a lightly struck cap stoppage, a dangerous condition arose, and if another round was fed without the chamber being cleared an explosion could occur in the breech.

(*c*) The unlocking plates which controlled the locking of the breech block, were liable to bounce when the breech block closed ; and if this occurred with a hang fire, the gun could fire with the breech unlocked.

(*d*) As the gun had been specifically designed for mounting on the Hispano Suiza engine, it was very difficult to provide a satisfactory mounting for it that would be suitable for use in turrets.

Several of these defects had been investigated by the French Air Ministry,[1] in particular they had found that a triple wire spring designed by the Chatellerault Arsenal completely cured the return spring trouble. They had also carried out trials with an inertia block fitted to the unlocking plates which appeared to reduce the bounce.

It was decided that the first order placed with B.M.A.R. Co. would be for the original pattern French guns, manufactured to the French drawings. This gun was introduced into the service and known as the Mark I. When drawings were available, B.M.A.R. Co. were to change over to the Air Ministry design—to be known as the Mark II, and all other production would be to that design.

The Mark II Hispano Gun

In view of the success of the ·303-inch Browning production, and the whole-hearted co-operation received from the B.S.A. organisation, it was decided that the drawings for the Mark II gun would be made in accordance with their methods, and with the advice of their production experts. In the summer of 1939, a number of Air Ministry draughtsmen were sent to the B.S.A. works at Birmingham to prepare the production drawings of the Mark II gun.

About the same time an endurance trial was carried out on one of the French made guns, which confirmed the necessity for modifications to overcome the defects listed above, and in consequence work on the Mark II design was accelerated. These trials also showed that the frequent lightly struck cap stoppages were not only due to weak return springs, but also to over-ramming of the cartridge on being fed in. The cartridge case of the Hispano gun was of the rimless variety and came to rest in the chamber by means of its short cone contacting the short cone of the chamber. To ensure the cartridge case being held rigid while the cap was struck, it was always made a little larger than the chamber, and then it ' crushed-up ' slightly as the breech closed. Owing to the high speed of the gun, the feeding of the round into the chamber was so violent that if the case was on the soft side, it ' crushed-up ' too much and moved so far into the chamber, that the firing pin could not strike the cap. It was expected that this trouble would be overcome by the use of cartridge cases of more consistent hardness.[1]

[1] M.A.P. File R.A. 1341 Part 2.

The main modifications incorporated in the Mark II design were :—

(*a*) Ribs were added to the top and bottom of the body to enable the gun to be mounted in a cradle for turret use and to provide datum faces for production.

(*b*) The attachment of the back block to the body was re-designed to increase its strength so that the breech block would not be blown out of the gun if the gun fired with the breech unlocked.

(*c*) The extractor was re-designed to improve the control of the case and increase the life of the extractor spring.

(*d*) As (*c*) increased the stiffness of the extractor, it was necessary to incorporate a buffered ejector and this involved re-design of the ejector, magazine catch and the magazine carrier.

(*e*) The unlocking plates were completely re-designed to incorporate an inertia block for reducing ' bounce '.

(*f*) Consequent on (*c*) and (*e*) considerable modifications were made to the breech block.

(*g*) The piston of the cocking cylinder was re-designed to facilitate production.

(*h*) A new return spring assembly was designed incorporating the triple wire spring.

(*i*) The sear assembly was re-designed to improve its performance.

One of the results of these modifications was that the majority of components of the Mark I and Mark II guns were not interchangeable. The French Air Ministry agreed to incorporate most of these modifications into their official design and an attempt was made to keep as many parts as possible interchangeable in the British and French made guns. In particular it was ruled by the Director of Armament Development (D. Arm. D.) that British and French guns were to be completely interchangeable for installation. To comply with this it was decided to retain the metric system in dimensioning drawings for the Mark II gun.

The various trials carried out during 1939 showed that although the original French made guns would fire over 700 rounds per minute, the reliability and life of the gun were greatly improved if the speed were kept down to 600 rounds per minute, and the latter was therefore specified as the normal speed for both the Mark I and Mark II guns.

Development 1939–1945

Early in 1939 it was decided to make a trial installation of the 20-mm. Hispano guns mounted in the wings of a Hurricane aircraft. After the declaration of war this project was put on high priority ; and limited production was commenced in 1940. By the beginning of 1940 the first Mark I guns were being delivered in increasing numbers from the British Manufacturing and Research Co. (B.M.A.R. Co.) factory, and the drawings for the Mark II gun were nearing completion. By that time it had been realised that armour would ultimately be fitted to all combat aircraft and it was decided that the 20-mm. Hispano gun would be the main armament for all fighter aircraft. The B.M.A.R. Co. factory was quite inadequate to supply the guns required for equipping the whole of the fighter forces so it was decided to build a shadow factory, run by B.M.A.R. Co. at Grantham, adjoining the existing works; and a similar factory, run by Messrs. B.S.A. at Newcastle-on-Tyne. A Royal Ordnance Factory was to be built at Poole, and part of the existing Royal Small Arms Factory at Enfield was to be given over to Hispano production. All these new factories, which were to manufacture the Mark II gun, were built and equipped during 1939 and 1940, production commencing in 1941.

By the summer of 1940 the first Spitfires equipped with 20-mm. guns were completed and one squadron took part in the air fighting during the Battle of Britain. The results were very disappointing, the guns proving so unreliable that the aircraft had to be withdrawn from operations. During that period another installation—the Beaufighter—with four 20-mm. Hispano guns was being completed on high priority. Whereas, in the case of the Spitfire aircraft, the gun was installed with its original 'moteur-cannon' type of mounting, with the Beaufighters it was not possible to use the muzzle brake fitted to the original gun. To absorb the extra recoil it was necessary to re-design completely the front mounting unit and embody a more powerful spring.

During the spring of 1940, an endurance trial was carried out on the first Mark II gun, and although the gun did well, a lot of trouble was experienced due to misfeeds from the magazine, and lightly struck caps caused by excessive 'crush-up', as previously experienced on the Mark I gun. This latter stoppage was so serious that urgent action was necessary. It was decided to decrease the length of the chamber by 2 millimetres, hence increasing the 'crush-up' by a similar amount; and also to increase the protrusion of the firing pin. This proved to be a complete cure, and the modification was carried out on the Mark I gun as well as on the Mark II.

By the beginning of 1941, the Mark II gun was being produced in quantity by the B.M.A.R. Co. factory, and considerable controversy centred round its introduction. By that time the Mark I gun was working fairly well in service, the main difficulties being due to the magazine, installation defects and poor maintenance. The whole idea of the design and development of the Hispano gun being taken over by the Director of Armament and Development was distasteful to B.M.A.R. Co.; and they maintained that the Mark II version of the gun was both more difficult to produce and less reliable than the Mark I.

The trouble experienced in getting the correct rate of fire from the first batch of the Mark II guns tended to confirm B.M.A.R. Co.'s contention. In order to get an unbiased view on the relative performance of the two Marks of gun, air firing trials were arranged at the Aircraft and Armament Experimental Establishment (A. & A.E.E.). Eight guns in all were used, including some of the first made at the Royal Small Arms Factory at Enfield. The report on the trials noted the superior finish on the Enfield guns. As a result of these tests, which showed little difference in the performance of either Mark of gun, the Mark II design was reviewed by the Director of Armament Development.

First it was recalled that there were no British drawings of the Mark I gun and the Mark II design was originally intended to provide production drawings suitable for general manufacture in Britain. It was realised, however, that many of the modifications were made as a result of French Air Ministry trials and had not been confirmed by trials in this country. Owing to the relaxation of drawing limits, the Mark II gun was, in general, easier to produce than the original French design. The position of the major modifications were :—

(*a*) *Body*. These modifications were necessary for strength, ease of installation and ease of production.

(*b*) *Back Block*. The same arguments applied as to the body.

(*c*) *Extractor*. Subsequent trials and Service experience with the Mark I gun confirmed the need for the most positive control of the empty case during ejection.

(*d*) *Magazine Carrier*. This was necessary consequent upon (*c*).

(*e*) *Unlocking plates*. The inertia blocks were incorporated on the advice of the French Air Ministry and there was no evidence as to their function. The new unlocking assembly plate was more difficult to produce than the original; involved more components and was more expensive.

(*f*) *Breech block*. These modifications were consequent upon (*c*) and (*e*).

(*g*) *Cocking piston*. This was definitely far simpler to produce than the original French design.

(*h*) *Return spring assembly*. This was a very great improvement over the French design and had been introduced retrospectively into all Mark I guns.

(*i*) *Sear assembly*. This new design was definitely more difficult to produce and more costly than the original design; moreover it appears to have been re-designed on theoretical considerations and its effectiveness was a matter of opinion.

From this survey only items (*e*) and (*i*) appeared questionable and upon further investigation no case could be made for the new sear assembly and the original design was introduced into the Mark II pattern. As regards the unlocking plates, it was agreed to carry out urgent trials to check the functioning of the inertia blocks. At that time, mid 1941, the Ministry of Aircraft Production had no experimental testing establishment with the necessary apparatus for carrying out such a trial, so it was done by the Road Research Laboratory, who had been doing some similar work for Messrs. Boulton Paul. These trials showed that the inertia blocks fulfilled no useful function and in certain cases increased the breech block bounce which they had been designed to cure. The unlocking plates were consequently re-designed, the inertia blocks being deleted. The new unlocking plates were very similar to the original type and were even easier to produce.

The changes did not satisfy B.M.A.R. Co., who maintained that although the modified extractor was necessary, a slight modification would enable it to be used with the original magazine carrier assembly. Trials carried out at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) with an extractor, which had been designed by B.M.A.R. Co. for use with the Mark I magazine carrier, showed that this extractor gave a high percentage of pierced rims and was unsuitable.

By 1942 the four factories were in full production and from time to time requests were received from them for design alterations to facilitate production.

As the requirements of the various factories were sometimes conflicting monthly meetings were arranged between the design authority (Research and Development (Armament)), the Aeronautical Inspection Department (A.I.D.), and the factories. At these meetings the alterations were discussed and if the majority of the factories agreed amongst themselves, the design authority generally agreed to put the alterations into effect and amend the master drawings.

During 1942 much trouble was experienced due to firing pins breaking. The cause proved to be faulty manufacture, but as all the factories were unable to obtain the required finish under production conditions, the firing pin was re-designed. This was the last modification of any importance made on the Mark II gun. By the middle of 1943, requests for drawing alterations from the manufacturers had ceased, and the monthly meetings were discontinued.[1]

When the belt feed mechanism[2] began to replace the sixty-round magazine in 1941 further difficulties ensued through insufficient recoil of the gun. To ensure correct recoil, the front mounting unit had to be adjusted separately for each aircraft. It was obvious that the unit originally designed for use on the Hispano Suiza engine was unsatisfactory for any installation fitted with belt feed mechanisms. During 1942, various alternative designs of front mounting unit were tried and by the end of the year a successful design had been produced. This was introduced early in 1943 as the Front Mounting Unit No. 3 ; its main advantage being that it required no adjustment, but gave correct recoil on all types of installations.

As stated earlier, the 20-mm. Hispano was originally intended for the equipment of both fighters and bombers, and Messrs. Boulton Paul carried out work on a Hispano turret during 1938 and 1939. By 1940, however, the Ministry of Aircraft Production decided that all manufacturing facilities were to be concentrated on existing guns, and the development of Hispano turrets was cancelled ; the result of this decision being that no 20-mm. turrets were used in operations. Late in 1941, however, work on 20-mm. turrets was re-started. It had always been obvious that the excessive length of the Hispano gun made it unsuitable for use in turrets, and trials were carried out to determine the effect of shortening the barrel. It was found that the barrel length could be reduced by twelve inches without affecting the functioning of the gun, but that there would be a slight reduction in muzzle velocity. This short barrelled gun was known as the Mark IV, but only a small quantity were made for experimental turrets. Apart from the short barrel and small modifications to the body to facilitate mounting in a cradle, it was identical with the Mark II gun.

About that time the Ministry of Supply Armament Design Department designed a gun to fire standard Hispano ammunition, but constructed on similar lines to the Army Sten Gun. This was rather optimistically known as the Mark III gun but it did not get beyond the design stage.

When the investigations into the shortened gun were commenced, a design of cradle to take the gun was also started in anticipation of a requirement for turret installations. The main object of the cradle was to obviate the use of the front mounting unit and a cradle incorporating a hydraulic buffer was designed by Messrs. B.S.A., in collaboration with the Research and Development

[1] M.A.P. File R.A. 1341 Part 7. [2] *See* Chapter 6.

branch of the Ministry of Aircraft Production. This proved to be unsatisfactory during trials at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) in the summer of 1942, and the cradle was redesigned to incorporate a mechanical recoil unit. When the cradle was submitted to the turret designers, it was found that it was unsuitable for installation in any turret then being designed. In consequence a completely new design was prepared to suit the latest Boulton Paul turret, and after successful trials the cradle was put into limited production as the 'Cradle Mounting Mark II.' The final turret selected for production was one designed by the Bristol Aeroplane Company, and not the Boulton Paul turret as anticipated, and in consequence the cradle had to be considerably modified to suit the Bristol turret; the modified cradle, known as the Mark III, went into production during 1944.

Re-design of the Mark II gun

During 1942 the Air Staff asked for an investigation into the possibility of speeding up the Mark II gun. A number of trials were carried out by the Research and Development (Armament) (R.D.Arm.) branch of the Ministry of Aircraft Production, and a development contract to speed up the gun was placed with the Molins Machine Company. The results of the trials indicated that the speed could be increased to 800 rounds per minute with only minor alterations to the gun, provided that a reduction in the life of certain components was accepted. About the same time a committee was formed to investigate the possibility of considerably reducing the weight of all equipment carried in fighter aircraft, the Armament Research and Development branch of the Ministry of Supply being asked to investigate the possibility of reducing the weight of the gun and feed.[1]

It was decided to take this opportunity to re-design the gun completely and to incorporate into the new gun the short barrel; increased rate of fire and light weight. One of the first questions to decide was the acceptable life of the new gun. Before the war a life of at least 20,000 rounds was expected for rifle calibre guns, and the acceptable life of the Hispano 20-mm. gun had been fixed at 10,000 rounds. It was apparent that under active service conditions few aircraft survived to give 10,000 rounds and an investigation was made to determine the actual life of guns on war service. The results were surprising: it appeared that very few guns ever reached 1,000 rounds, and the majority only fired a few hundred before the aircraft crashed or was lost in action. There was obviously no point in arming at a 10,000 round life, and the Air Staff were asked to accept one of 1,500 rounds.

The design of the new gun was carried out by the Armament Research and Development (R.D.Arm.) drawing office at Enfield, and prototype models were made, and all experimental firing was carried out at the Royal Ordnance Factory (R.O.F.) at Poole. As a result of experience with the various factories making Hispano guns, the R.O.F. Poole was used as a 'parent firm.' The first of the new guns was ready in 1943, being known as the Mark V.

The final gun was 30 lb. lighter than the Mark II and had an average rate of fire of 820 rounds per minute. The breech block assembly was found to have a very short life and a number of feed stoppages were experienced, due to the belt feed mechanism being unable to feed the rounds up in time to engage the

[1] M.A.P. File R.A. 1341 Part 6.

breech block. A number of small modifications were made and the gun speed reduced to 750 rounds per minute; the weight being further reduced by 5 lb. Subsequent experience with production guns in service showed that the average life of the smaller components was 2,500–3,000 rounds, while the body and barrel were good for at least 5,000 rounds.

The main changes made in the design of the Mark V gun were :—

Body.—The top mounting slides were eliminated and a number of lightening cuts made. The cocking cylinder was also removed.

Barrel.—Length reduced by 12 inches and the thickness considerably reduced at the forward end.

Back Block.—Buffer spring strength increased and thickness of back block reduced all round.

Breech Block.—Small modifications only to reduce weight.

Unlocking Plates.—Considerably lightened by reducing section at centre of plates.

Extractor.—Slope modified to reduce possibility of pierced rims.

Front Mounting Unit.—Completely re-designed and made much shorter, on the same principle as the No. 3, Mark I, front mounting unit.

The majority of the weight was saved in the barrel and body; the elimination of the cocking cylinder meant also the abolition of pneumatic cocking, and this meant a further saving in the weight of the complete installation. It had been found after investigation that the cocking unit was never used in the air; the guns being cocked by the armourers on the ground before take off. It was therefore agreed by the Air Staff that on the new gun cocking would be a ground operation only; a hand-operated cocking unit was designed that could be quickly attached and detached from the gun as required.

The ground trials of the Mark V gun were completed successfully by the summer of 1943, and air firing trials commenced at the Aircraft and Armament Experimental Establishment (A. & A.E.E.). Owing to its lighter weight and higher rate of fire, the gun was found to be more sensitive to mounting conditions than the Mark II, and considerable trouble was caused by erratic recoil. After a number of trials lasting the remainder of the year, it was decided that the No. 3 type of front mounting unit was not suitable for the high speed of the Mark V gun. An American design of mounting unit fitted to the American made Mark II guns had been found to give very good results on flexible mountings.[1] This was known as the 'Edgewater' unit, and a new front mounting unit was designed for the Mark V gun incorporating the 'Edgewater' principles. This proved very successful; it eliminated the worst of the recoil troubles; and went into production early in 1944.

American made guns

As previously stated the Hispano 20-mm. gun had also been adopted by the U.S.A. To supplement British production, the Ministry of Aircraft Production were obtaining a number of American made Hispano guns to meet requirements for the end of 1942 and 1943. All information on the British gun had been made available to the United States Army Ordnance, and every endeavour had been made to presuade them to adopt the various modifications made to the British gun.

[1] M.A.P. File R.A. 1341 Part 6.

Early in 1942, the first American made guns were received and trials were carried out on the Inter-Service range at Pendine and in the air at the Aircraft and Armament Experimental Establishment (A. & A.E.E.). The results were disturbing. Frequent misfeed and lightly struck cap stoppages were experienced and the life of several small components was exceptionally short. For reasons that were not clear, the United States Army Ordnance had refused to adopt the British modifications incorporating the 2-mm. 'crush-up' and the triple wire return spring.[1] It was found that in consequence these guns would suffer from the same defects as the original French guns. An endurance trial was arranged to compare the performance of the British Mark II gun and the American equivalent.[2] This trial was carried out in October 1942 and gave the following results :—

Gun.	Rounds Fired.	Lightly struck Caps.	Misfeeds.	Total Stoppages.
American M2, No. 29552	4,095	20	34	67
American M2, No. 28207	3,705	31	59	97
American M2, No. 27943	2,610	36	40	94
British Mark II*, No. F.6097	5,012	7	6	19

Gun No. 27943 fired on a more severe programme ; all firing being in fifty-round bursts. Together with the earlier trials, this proved conclusively that the American M.2 gun was greatly inferior to the British Mark II as regards frequency of stoppages and could not be regard as a satisfactory service weapon.

By the end of 1942, the supply position had changed ; it being decided that the Spitfire V—originally designed for four 20-mm. Hispano guns—would be fitted with two 20-mm. and four ·303-inch (Browning guns), thus reducing the number of 20-mm. guns required. The four factories making the gun were in full production and in particular the Royal Ordnance Factory at Poole—originally laid out to produce 250 guns per month—was producing four times that figure, which meant that current requirements for guns could be met from British production alone. In view of this and the poor performance of the American made guns, it was decided that no American guns would be used on R.A.F. aeroplanes.[3] As some thousands of them had been delivered, an attempt was made to modify them to make them suitable for ground use ; the length of chamber being reduced by 2-mm. and the triple wire return spring fitted. The effect of the first modification was to render the barrel assembly non-standard with the Mark II guns as regards installation. A number of American made guns were modified, but only a limited number were ever fitted to ground mountings and none were used in operations.

The introduction of the No. 4 Front Mounting Unit for use on the Mark V gun was the last change of any importance that was introduced for service use. A certain amount of experimental work continued on the 20-mm. gun, mainly to improve it for use in turrets. Messrs. Molins Machine Company continued their investigations into increasing the speed of the gun and achieved a speed of 1,000 rounds per minute on an experimental gun.

[1] M.A.P. File R.A. 1350 Part 2. [2] M.A.P. File R.A. 1350 Part 1.

[3] M.A.P. File R.A. 1350, Part 2, Encl. 56A.

CHAPTER 5

VICKERS 40-mm. CLASS 'S' GUN

Early history

At the end of the First World War, the R.A.F. held a number of 37-mm. C.O.W. (Coventry Ordnance Works) guns which were automatic in operation and firing an explosive shell of 1½ lb. weight. Various trials were carried out with these guns from time to time, but were never very satisfactory and the gun was not considered necessary for air to air fighting. Trials were also carried out to assess its suitability as an anti-submarine weapon, but although the weapon was efficient in itself the sighting problems had not been solved at that time, and aircraft were not sufficiently powerful or robust to mount such a heavy weapon.

Development

With the development of heavier aircraft, the question of large calibre weapons firing explosive shells was investigated in 1936, it being considered that such a weapon would be capable of destroying an aircraft with one hit, if a shell with a minimum weight of about two pounds was used. This ruled out the use of the 37-mm. C.O.W. gun and the Director of Armament Development (D. Arm. D.) drafted a provisional specification for a 'two pounder' aircraft gun.

In the meantime, Messrs. Vickers Armstrong had already designed an anti-aircraft gun for the Admiralty and in February 1938, in anticipation of an Air Ministry requirement for a large calibre gun, had commenced a design for an aircraft gun to fire the standard Naval 2-pounder ammunition. The gun was of the long recoil type and followed the 37-mm. C.O.W. gun in general layout. Feed was from a 15-round spring driver magazine, an improvement on the 5-round hopper system of the C.O.W. gun.

The design was completed by the end of 1938 and submitted to the Air Ministry early in 1939. Messrs. Vickers proposed that this gun should be used for air to air fighting, being mounted in a gun turret in a Wellington aircraft equipped with a rangefinder and predictor sight. It was claimed that such an installation would be able to engage enemy aircraft at long range, long before the normal armament of the enemy would be effective.

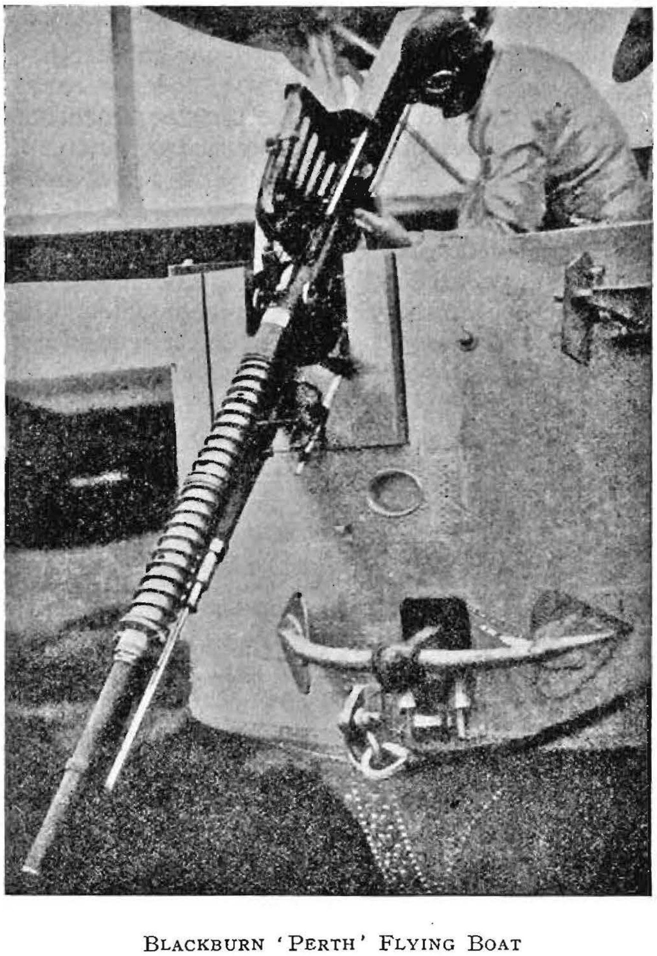
Early in 1939 a contract was placed with Messrs. Vickers for the design and construction of one 40-mm. automatic aircraft gun. This was completed during the summer of 1939, and trials commenced at Vickers Crayford works during September. These development trials were completed by the end of the year,[1] and, in March 1940, successful ground tests were carried out by the Ordnance Board, who recommended that the 40-mm. gun was satisfactory for service use. Owing to pressure of other work, there was considerable delay in completing the Wellington in which air trials of the gun were to be carried out. In May 1940, Vickers suggested that air trials of the gun should be carried out in a fixed gun installation of the Beaufighter type, and that the tooling necessary to produce the gun should be commenced in anticipation of its adoption.

[1] M.A.P. File C.S.B. 31031/1

By that time, however, the experience of our own bombers operating over enemy territory showed that 40-mm. shells were unlikely to destroy an aircraft with one hit ; some of our bombers had returned with as many as six direct hits by 40-mm. anti-aircraft shells. It was considered by D. Arm. D. that, weight for weight, a 40-mm. installation would be less effective than the 20-mm. Hispano, and so, although work on the 40-mm. as an air to air weapon did not cease, it was relegated to low priority.

Development of the 40-mm. as an anti-tank weapon

The land fighting of 1940 showed that the destruction of enemy tanks was a major problem, and that the immobility of anti-tank guns enabled the enemy to get round them. In January 1940, D.C.A.S. asked for the question of attacking tanks from the air to be examined. It was considered that the armour penetration of the 20-mm. Hispano gun would be inadequate, but that an A.P. projectile could be developed for the 40-mm. gun that would give sufficient penetration to defeat the armour of any tank up to and including the German Mark IV. Early in 1941 it was decided to install the Vickers 40-mm.

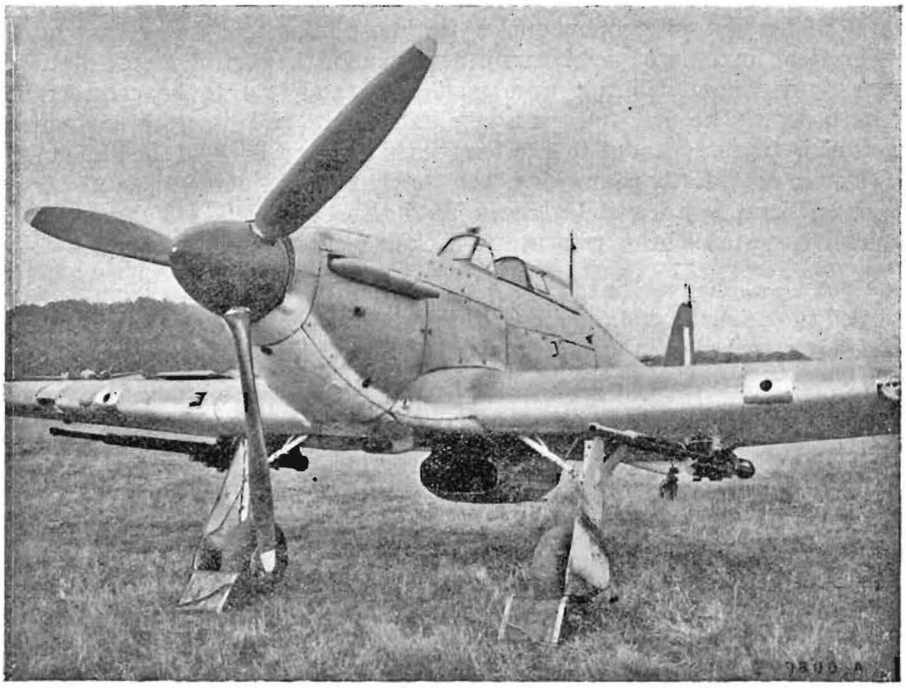


Blackburn 'Perth' Flying Boat
Fitted with 37-mm. C.O.W. Gun—1935

gun in a Beaufighter for air trials, and a development order for 100 guns was placed with Messrs. Vickers. In the meantime the Hawker Aircraft Company commenced the design of a special Hurricane (Mark IID) to take two 40-mm. guns—one under each wing.

By the summer the air trials in a Beaufighter had been successfully completed ; 100 rounds being fired without the gun giving any trouble. In June the order on Vickers was increased to 500 and the gun was introduced into the service as the Vickers 40-mm. Class ' S.' The first Hurricane equipped with two of the original experimental guns was sent to the Aircraft and Armament Experimental Establishment (A. & A.E.E.) in September 1941.[1] These trials were satisfactory and later in the year, a demonstration against a Valentine tank, confirmed the suitability of the installation for the attack of Armoured Fighting Vehicles (A.F.V.).

It was decided that one squadron of Hurricanes so equipped was to be formed in the Middle East at the earliest opportunity, and the end of February 1942 was fixed as a target date for the despatch of the necessary equipment. This meant that the first 30 guns off production were to be sent overseas for operational use ; leaving only a few months to overcome the various difficulties that inevitably arise when a new weapon is put into production. It was decided that in addition to the usual ground acceptance trials, each of the first batch of guns would be subject to air trials in a Hurricane before despatch overseas.



HURRICANE IID FITTED WITH VICKERS 40-MM. 'S' GUNS

[1] M.A.P. File C.S.B. 31031/1.

The seriousness of the position will be realised when it is recalled that the first 200 production Vickers G.O. guns were unsuitable for operational use and relegated to training ; and the first production Hispano guns were considered unfit for firing anything but ball ammunition and were used for training only.

The first four guns were forwarded to the Aircraft and Armament Experimental Establishment (A. & A.E.E.) in December 1941, and although these guns had passed the ground acceptance tests successfully, trouble was experienced during the air trials from mal-ejection of the empty cartridge case. This was surprising because a large number of rounds had been fired in the experimental guns without a hint of such trouble. Upon investigation it was found that all experimental firing had been conducted with ammunition manufactured by Messrs. Vickers, but owing to the large production orders for ammunition, cartridge cases were being issued from Naval stocks which had been manufactured at a number of other factories.

It was found that most of the mal-ejections occurred with cartridge cases made by Kynoch ;[1] these were considerably softer than those made by Vickers and, after firing were so tight in the chamber that the rim was torn. Owing to difficulties of supply it was impossible to specify Vickers made cases only for air use, but it was found that the Kynoch cases would eject satisfactorily if oiled before loading. The use of oiled cartridge cases had always been considered bad practice in the British Services, but the Naval Oerlikon gun used an oiled case, and it was decided to adopt this practice for the Vickers 40-mm.

A number of small defects were also revealed during the course of the air trials on the first production guns ; the most important being that under accelerations imposed by aerobatics the springs for the cartridge nose platform and cartridge nose deflector were inadequate and had to be considerably strengthened. The first 100 guns were hand made and a certain amount of functioning trouble was due to interferences in different parts of the mechanism which were not strictly to drawing. Of the first 30 production guns 27 passed the air tests and were despatched to the Middle East at the end of February 1942. The remaining three being returned to Vickers works for rectification.

As a result of the first air trials, it was apparent that many small defects were revealed under such conditions which did not come out in routine acceptance trials. It was decided therefore that all 40-mm. guns would have to pass an air firing trial before acceptance, and a special Gun Proofing Flight was formed at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) for that purpose. The first issue of guns were in action in the Western Desert from June 1942 until November 1942, and throughout that period no serious faults appeared in the guns or installations ; the majority of stoppages being due to faulty ammunition.

During early actions an unexpected fault in the design was revealed. In the Hurricane IID, the guns were mounted under the wings with the barrels projecting several feet forward of the leading edge. In the event of the aircraft making a ' belly landing,' the gun barrels hit the ground and, if the gun was loaded, the round in the breech would be fired, and as the barrel would be choked with earth or sand, it would burst. It was found that the barrel was

[1] M.A.P. File C.S.B. 31032/1.

forced back against the recoil spring and when the gun was loaded, the barrel extension tripped the sear and fired the gun. In normal use the barrel only moved back after the gun had fired. Fortunately the trouble was corrected by a very minor alteration to the automatic sear which could be easily carried out by the squadron armament staff.[1]

It had also been reported from the Middle East, that the ammunition capacity of the 15 round magazine was inadequate, so Messrs. Vickers designed a magazine to hold 30 rounds, and also a belt feed mechanism. The former was found to be too bulky for wing installations and the project was dropped, but an experimental belt feed mechanism had already been tried on the prototype gun,[2] and this was now re-designed for production. From the end of 1942 onwards the provision of 40-mm. guns became less urgent and work on the belt feed mechanism continued on low priority.

The only major modification made to the gun was to fit a re-designed liner in the oil buffer to cater for the increased recoil loads due to the use of a 3 lb. armour piercing projectile; this liner being completely interchangeable with the original. As the first 100 guns were hand made, they were not interchangeable and during their air proof trials a number of small modifications had been made, the most important of which have already been mentioned. It was decided that guns subsequent to the first 100 would be known as the Mark II,[3] and would have all the earlier modifications incorporated and would be interchangeable.

The Air Ministry system of drawing control and modification procedure was applied to the Mark II gun. The number of modifications incorporated in the Mark II design were :—

(*a*) Introduction of the three-port liner.

(*b*) Alterations to the profile of the cartridge nose deflector.

(*c*) Introduction of the rear mounting attachment.

(*d*) Introduction of new type locking screws for the trunnion block.

The following modifications were made to the magazine :—

(*a*) Introduction of the Mark I loading handle.

(*b*) Introduction of the handle locking plunger.

(*c*) Introduction of cartridge retaining spring on the magazine deflector.

By the end of 1942, the 40-mm. armour piercing projectile was not effective against the armour of the latest German tanks, and it was decided to try and improve the armour penetration by using 'Littlejohn'[4] type of high velocity ammunition involving considerable modification to both the gun and magazine.[5] One gun was modified, and, after considerable delay, air trials were

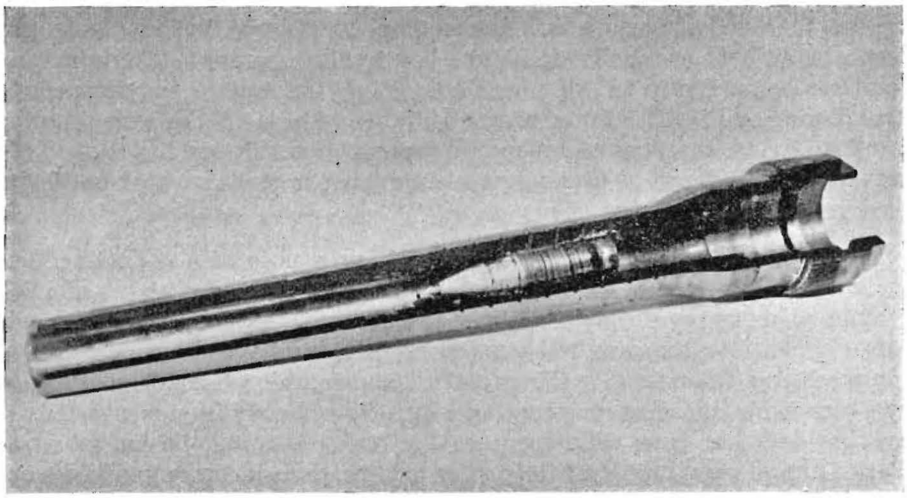
[1] M.A.P. File C.S.B. 31032/2. [2] M.A.P. File C.S.B. 31034 Encl. 2A.

[3] M.A.P. File C.S.B. 31032/1.

[4] A small calibre high density bullet of tungsten-carbide steel was fitted with driving bands to fit the bore of a larger gun. As the bullet emerged from the barrel, an attachment on the muzzle of the gun swaged the driving bands over the high density core, thus ensuring that the bullet had a good ballistic shape.

[5] M.A.P. File C.S.B. 31031/2.

carried out at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) during May 1944. These trials were not very successful and it was reported that the modified gun was not sufficiently reliable for Service use. By that time the 40-mm. ' S ' gun was no longer an urgent requirement and no further work was done on this project.



MUZZLE ATTACHMENT (SECTIONED) FOR USE OF 'LITTLEJOHN' HIGH VELOCITY AMMUNITION

Although originally designed for air to air fighting, the ' S ' gun had been adopted as an anti-tank weapon, but by the end of 1942, the rocket projectile had been introduced into the service. This was considered to be more suitable for anti-tank work and it was decided that the ' S ' gun would not be issued to the 2nd Tactical Air Force for operations in Europe. A small number were transferred to the Far East, but were only used on a limited scale.

There were two reasons why the ' S ' gun was replaced by rocket projectiles for anti-tank work. First, the 60 lb. H.E. head was more destructive against tanks than the 40-mm. A.P. projectile ; it was also far more destructive against soft skinned M.T. vehicles, against which the 40-mm. A.P. was of little use. Secondly, aircraft carrying the 40-mm. gun had to have specially designed wings and could not carry any alternative load ; this greatly restricted the tactical use of the aircraft. The R.P. on the other hand could be fitted to the normal fighter-bomber as an alternative to the bomb load, and it was this, rather than the greater destructive power of the 60 lb. head, that finally decided against the use of the ' S ' gun in Europe.

Although not as destructive, the 40-mm. ' S ' gun was far more accurate than R.P. Considering the short time spent on its development, and the conditions of extreme urgency under which the early models were produced, the gun proved very reliable in service use and was easy to maintain.

CHAPTER 6

FEED MECHANISMS FOR 20-mm. GUNS

Two methods of feeding the Hispano 20-mm. gun were used in the Royal Air Force ; firstly by a magazine which held sixty rounds and secondly with a belt feed mechanism. The feed was always the weakest part of the Hispano installation causing more stoppages than any other item ; and this applied until the end of the war in spite of continual attempts to improve it. The original French guns were equipped with a sixty-round, spring driven magazine, and during the early trials its reliability compared favourably with other parts of the gun. It was realised quite early in the development of the gun, that the magazine then in use would not provide sufficient ammunition for the modern fighter, and the Air Staff asked that the question of providing a belt feed be investigated.

Magazine feed

The first installations were intended to use the sixty-round magazine. As this magazine did not appear to suffer from any particular troubles, provision of drawings for the gun was considered the more urgent, and thus, when the design of the Mark II gun was commenced, the magazine remained fundamentally the same. When it came to producing magazines, a very serious difficulty appeared. The end plates, which carried the spiral channels in which the rounds moved, were machined from solid steel in the French magazines ; a most expensive and laborious method requiring the use of special machine tools. To alleviate this problem, the British Manufacturing and Research Company (B.M.A.R. Co.) cast the end plates in aluminium alloy ; but even so the firm was not able to produce magazines in the quantities required, and a contract was placed with the Austin Motor Company. This firm completely re-designed the magazine, making it entirely of steel pressings spot welded together, the original design being considered impossible to produce in quantity.

While D.Arm.D agreed on the difficulty of producing the original design, he and his staff had grave doubts about the Austin design : it had not been through any trials, and Austin's had no previous experience of gun design. However, as the supply position was very serious, and it appeared that guns would shortly be produced without any magazine to use with them, D. Arm. D. agreed to accept the firm's design. The first Austin magazines were produced early in 1940, and although they gave a certain amount of trouble they passed their acceptance tests. By the summer of 1940, Austin's were in full production, but in August of that year there was a complete breakdown in deliveries, due to the failure of the magazines to pass the acceptance tests as laid down by the Chief Inspector of Small Arms (C.I.S.A.),—Research and Development Armament (R.D. Arm.) were asked to investigate.

It appeared that in re-designing the magazine for ease of production, deviation from the original design had occurred in several small but important details. By that time, France had fallen, so no help could be obtained from the Hispano Suiza Co. As Austin's had used English dimensioning, it was extremely difficult to find out the exact variations between the French and Austin drawings. Moreover the driving springs used by Austin's were definitely inferior to those of French manufacture; as was the general finish of the magazines. In order to prevent a complete hold up of delivery, the acceptance tests were reduced in severity; in particular the elevation at which the magazines were fired was reduced from 80° to 45°.

In the meantime, a foreman in the Austin factory submitted an idea for attaching a spring driven 'booster' to the side of the magazine, which ensured correct feeding of the rounds, and, although rather clumsy, considerably improved the performance of the magazine. As both the Austin designers and R.D. Arm. failed to produce any alternative solution, the 'booster' was accepted and introduced, retrospectively, to all Austin magazines.

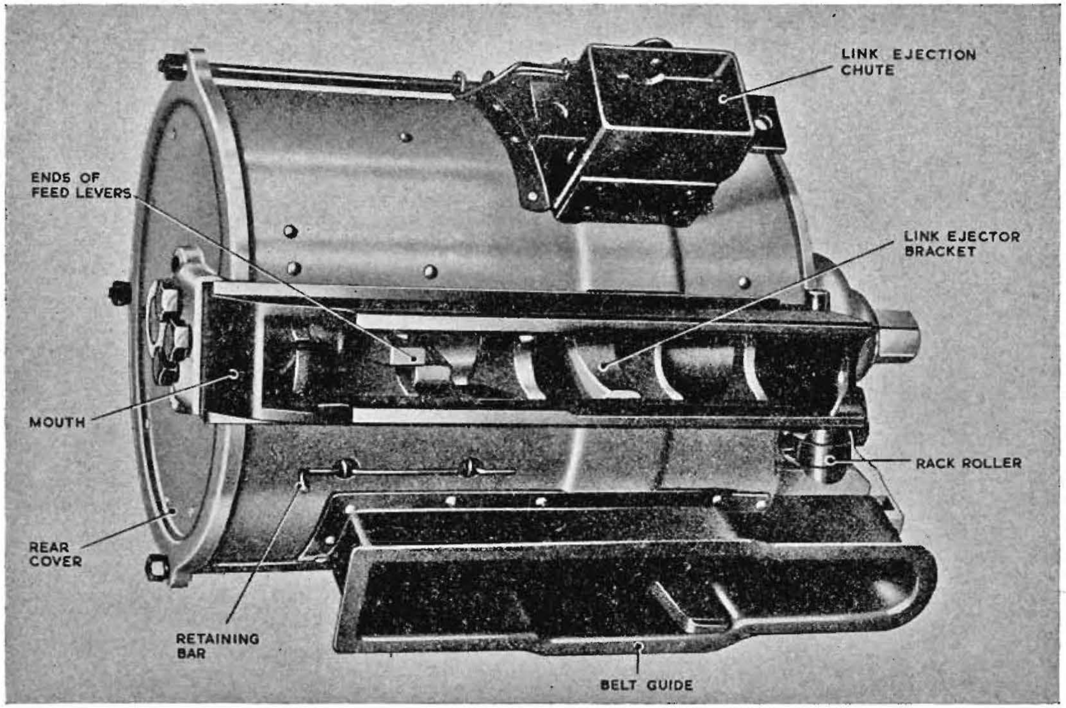
These magazines were definitely sub-standard both as regards design and manufacture, and were a constant source of trouble as long as they were in the service. To achieve a satisfactory reliability they called for a very high standard of maintenance on the part of the Royal Air Force armament ground staff. The B.M.A.R. Co. magazines were far more reliable, but the cast end plates had a very short life and fractured easily; production of this type ceased once Austin's were in full production.

Belt feed mechanism

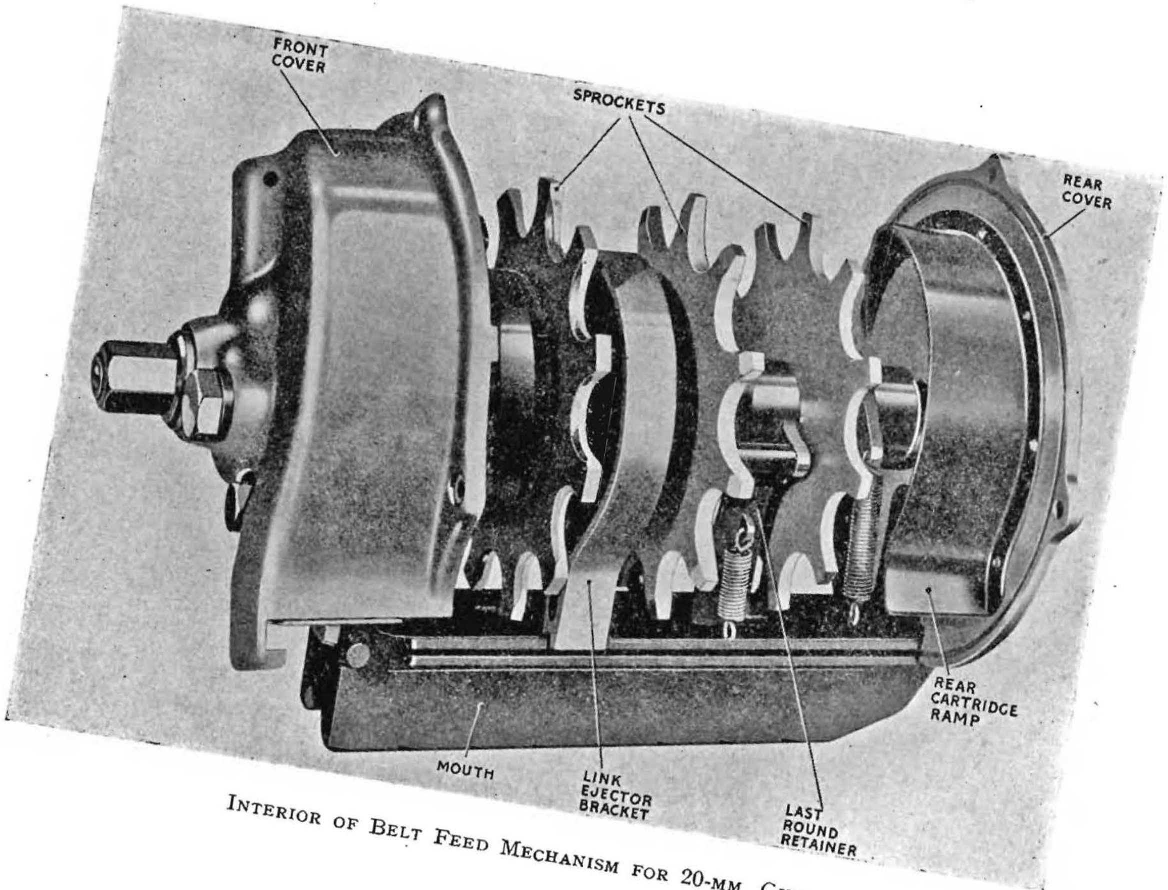
The unsatisfactory nature of the magazine made the provision of alternative methods of feed a very urgent problem. As already mentioned, the need for a belt feed was realised early in the trials of the Hispano 20-mm. gun, and a definite requirement was formulated by the Air Staff; a number of designs being put in hand during 1938. Early in 1939 six designs were under consideration, and prototype models of various designs were constructed and tested during the year. Only one however,—the Hydran Products feed—showed any real promise and production of this type was started early in 1940.

In the meantime, the Chatellerault Arsenal had been working on a design of belt feed for the Hispano 20-mm. gun, and during the spring of 1940, a sample of this feed, and a complete set of drawings were brought over from France. A short ground trial was carried out and it was thought to be far superior to any design then being developed in this country. This feed used a disintegrating steel link belt, and was spring operated, the spring being tensioned by the recoil of the gun. It was interchangeable with the magazine and needed only a small modification to the gun, and an order for fifty was placed with Messrs. B.S.A.[1] The ground and air trials of this mechanism showed it to be greatly superior to the Austin magazine both for installation and reliability and it was cleared for production in September 1940 being introduced into the service as the Belt Feed Mechanism (B.F.M.) Mark I and work on all belt feeds was stopped. The Hydran Products magazine failed completely in air trials of the production model, and work on this was also stopped.

[1] A.M. File S. 46399.



BELT FEED MECHANISM FOR 20-MM. GUN



INTERIOR OF BELT FEED MECHANISM FOR 20-MM. GUN

At the time of its introduction the Mark I mechanism was not fully developed, and in consequence development and production had to proceed together. As the tensioning of the belt feed spring depended on the recoil of the gun, it was necessary to make some changes to the front mounting unit to ensure full re-coil. One of the most unsatisfactory features of the Mark I mechanism was the method of tensioning the spring. The roller, rack and cam by which this was done appeared to have a very harsh action. A number of attempts to design a more satisfactory method were made by various organizations, including the Royal Aircraft Establishment (R.A.E.), but none were successful, and no alteration to the tensioning device was ever made.[1]

The first belt feeds were delivered early in 1941 and by the Spring they were reaching the Service in quantity. A considerable amount of difficulty was experienced at first; in addition to the inherent troubles of the feed itself, it was also sensitive to gun recoil and make-up of the belts. The majority of these early troubles were due to poor maintenance and disappeared when the R.A.F. ground crews became more experienced. In addition a number of small improvements were made as a result of the investigations during manufacture. By the middle of 1941, the Mark I belt feed having been proved to be definitely superior to the magazine as regards reliability, no further installations were designed for magazines and, as far as possible, existing magazine installations were replaced with belt feed mechanisms.

In August 1942, the parent firm of contractors (Molins Machine Co.), reported that arising from a series of trials their designers had found that the functioning and reliability of the B.F.M. could be considerably improved by fitting an extra sprocket to support the nose of the round, and by chromium plating the ramp in the front cover.[2] Air trials were carried out at the Aircraft and Armament Experimental Establishment (A. & A.E.E.), with four belt feeds modified as suggested, and results completely confirmed Messrs. Molins' claims. It was decided to introduce this modification forthwith, and all mechanisms fitted with the extra sprocket were known as the Mark I*.

The Marks II and III belt feed mechanisms

Although far less bulky than the magazine, the Mark I B.F.M necessitated a 'blister' on the wing when fitted to wing gun installations. As aircraft speeds increased these protuberances became increasingly unpopular with aircraft designers and D. Arm. D. was pressed to develop a feed of lower overall height. During 1941 a development contract was placed with Messrs. Molins to produce a flat feed and a prototype was ready for trials by the end of the year. It was on the same principle as the Mark I, but used two sprocket shafts and an elongated ramp, and was several inches lower than the Mark I. The firing trials with this mechanism proved very disappointing and as the trouble appeared to be fundamental to the design, the project was dropped.

This feed was known as the Mark II, and in the course of development it had been shown to Vickers Supermarine design staff. They were so impressed with its possibilities from the installation point of view that when D. Arm. D.

[1] M.A.P. File R.A. 2594/1. [2] M.A.P. File R.A. 2594/2.

decided to cease development of this type, Messrs. Vickers Supermarine commenced work on a design of their own, similar to the Mark II. This feed however suffered from the same fundamental defects, and for this reason D. Arm. D. was not in favour of producing it. However, he agreed to have some samples made up which were, after some delay, manufactured by Molins Machine Co. The first ground trials held in September 1943 showed them to be little better than the Mark II, and this was confirmed by air trials at A. & A.E.E. at the end of the year. Messrs. Supermarine attempted to improve its performance by various means, but by the end of the war had not succeeded in producing a satisfactory feed.

In view of the interest taken in the Supermarine feed, Messrs. Molins decided to make another attempt to design a flat type.[1] They retained the layout of the Mark II, but completely re-designed the detail mechanism, and preliminary trials took place in June 1944. Although an improvement on the Mark II, it was still not satisfactory, but after further adjustments and minor modifications, was submitted for air trials at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) in the following September. These trials showed that the new model was comparable with the Mark I* both as regards reliability and performance, and it was put into production as the Mark III Belt Feed Mechanism. The war in Europe ended before any quantity of these were produced and none were issued for operational use.

Driving springs for belt feed mechanisms

The driving spring of the belt feed had always been one of the most troublesome components; both the quality of the strip used and the manufacture of the spring varied considerably. When assembled into belt feeds this led to a variation in performance both as to the maximum load that could be put on the spring before the clutch slipped and the maximum belt pull given. To ensure that only serviceable mechanisms were used in squadrons, the R.A.F. Servicing and Maintenance Branch instituted a test for driving springs, and, as a result, rejected a large number already in service. An investigation was made by R. D. Arm. early in 1944, and as a result the manufacture of driving springs was standardised. It was decided that the spring steel strips would be made by one firm only to ensure constant quality, and this led to a marked improvement in performance and reliability; all defective springs in service being ultimately replaced by the new type.

The Marks IV and V belt feed mechanisms

Some difficulty was experienced in fitting the standard type of B.F.M. into the de Havilland Hornet aircraft, so the link ejection chute was modified to suit the Hornet installation. This mechanism was produced in limited quantities and known as the Mark IV.

When the design of the Mark V Hispano 20-mm. gun was commenced,[2] Messrs. Molins were instructed to investigate the possibility of reducing the weight of the Mark I* Belt Feed Mechanism. They produced a design identical

[1] M.A.P. File R.A. 4571. [2] *See* Chapter 4.

and interchangeable with the Mark I*, except that the end covers and sprockets were made from aluminium alloy, and was five pounds less in weight. After service trials it was introduced as the Mark V B.F.M., deliveries off production being made in November 1944. By the end of the war the Mark V B.F.M. was gradually replacing the Mark I*, but the majority of squadrons were still equipped with the latter. Although the B.F.M. was more difficult to service than the gun and was a more frequent source of stoppages, it was, none the less, far superior to any other design available at the time of its introduction ; and in spite of continual efforts during the war, no better was ever produced.

CHAPTER 7

FIRE CONTROL MECHANISMS

With the exception of the Lewis and Vickers G.O., all guns used in the Royal Air Force in the Second World War were fired by means of a remote control mechanism. Pneumatic firing mechanisms were the first, and most widely used, but they were being replaced by electric mechanisms by the end of the war. All design and development work on firing control mechanisms, unlike that on guns, was carried out by private contractors to the requirements laid down by the Director of Armament Development (D. Arm. D.). Most of this work was done by the Dunlop Rim and Wheel Company, a subsidiary of the Dunlop Rubber Co., and in general the mechanisms had been fully developed by Dunlop before they were submitted to D. Arm. D., so very little subsequent development was necessary.

At the time of the introduction of the ·303-inch Browning gun, the synchronising gear was the standard method of firing the fixed guns of fighter aircraft. With the introduction of the eight gun fighter the synchronising gear was no longer required and some other method had to be devised.

There were four possible methods :—

(*a*) Cable control.

(*b*) Electric control.

(*c*) Pneumatic control.

(*d*) Hydraulic control.

It was considered that cable control of eight guns was not possible as the pilot would have to use considerable force to fire the guns. Electric control was not favoured for two reasons ; first, solenoids for firing the gun would have been very heavy, and secondly, the electrical services in most fighter aircraft were already overloaded. It was finally decided to develop both pneumatic and hydraulic firing gears for the ·303-inch Browning gun.

Pneumatic and hydraulic gears

The pneumatic gears were developed by the Dunlop Rim and Wheel Co., and the hydraulic type by the Palmer Tyre Co., and trials of the two types were carried out during 1938. Both gears worked equally well, and the adaption of one or the other depended on the services available in the aircraft, rather than the intrinsic merits of the system. Finally it was decided that the pneumatic type would be used on all fixed gun installations and the hydraulic system on hydraulic gun turrets.

The Dunlop system consisted of an air container, fed from an engine driven air compressor, which supplied air, through a filter and reducing valve, to the gun firing button valve. The firing button fed air to the rear sear release unit and fire and safe units attached to the guns. The air container was maintained at a pressure of 200 lb. per square inch, which was reduced to 150 lb. per square inch at the pneumatic units, although the guns would fire with the pressure as low as 110 lb. per square inch. This system remained the standard for fixed ·303-inch Browning guns throughout the war ; it gave very little trouble and no major modifications to it were necessary.

The Palmer hydraulic gear was fitted to all early Frazer Nash turrets, and a certain amount of trouble arose with the system due to the fact that it was operated from the turret hydraulic power. During the operation of the turret, back pressures were liable to develop in the system, which adversely affected the operation of the sear release units. It was evident that the firing catch in the turret was closely bound up with the design of the turret, and the firing catch was considered part of the turret when ·303-inch Browning guns were fitted.

Firing control in turrets

Turret designers produced firing controls to suit their own turret systems. Boulton Paul developed an electric firing control in which a solenoid operated the rear sear ; the ' fire and safe ' mechanism being hand operated. The sear release unit was heavy and bulky compared with the hydraulic and pneumatic units, but was more suitable for an electrically operated turret. In addition, this system was more suitable for operation in conjunction with taboo gear for preventing the gunner hitting his own aircraft. Later types of Frazer Nash turrets used the Boulton Paul electric firing control, and it was also used on one of the Bristol Aeroplane Co. turrets.

An electric solenoid for firing the sear release unit, known as the ' Magnavox ' unit, was developed by the United States Army Ordnance for firing the ·5-inch and ·30-inch Browning guns. This was a neater and more efficient design than the Boulton Paul, and, when supplies became available in this country, it was used on the latest types of Frazer Nash turrets. It was also fitted to the Browning guns of American made aircraft used in the Royal Air Force.

Firing units fitted to 20-mm. Hispano guns

When the 20-mm. Hispano gun was adopted, pneumatic firing control was necessary because the Mark I and Mark II guns were designed for pneumatic cocking. Messrs. Dunlop's designed a sear release unit for the Hispano gun, which, after trials early in 1938, went into production at the end of that year. The layout of the system was similar to that used for the ·303-inch Browning gun and many components, such as air containers, filters and reducing valves were standard to both systems. In addition to the sear release unit, two additional items were used in the original Hispano control system. A cocking valve was fitted for cocking the guns and a gun safety valve was connected with the undercarriage so that the guns would not fire when the undercarriage was down ; the latter was fitted to the early Spitfires only.[1]

This system was used successfully on the Spitfire and Hurricane installations, but on certain other aircraft, such as the Beaufighter, the pilot was so far from the guns that the length of air pipeline from the firing button to the sear release unit became excessive and gave rise to an appreciable time lag between pressing the firing button and the guns opening fire. To overcome this an electric/pneumatic firing control system was used in which the standard pneumatic

[1] M.A.P. File R.A. 1031.

units were used adjacent to the guns, but were controlled by a solenoid operated valve operated by the pilot. In other words although the actual firing of the guns was pneumatic, the connection between the pilot and the gun bays was electric. This system was used on all aircraft after the Spitfire and Hurricane.[1]

Both systems gave little trouble in service, but a number of small modifications were carried out as a result of service and manufacturing experience, all of which were embodied in the Mark II sear release unit, which differed from the Mark I in certain small details only. When the design of the Mark V Hispano gun was commenced, Messrs. Dunlop's were requested to redesign the pneumatic sear release unit with a view to reducing its weight.[2] Trials of this unit, which was known as the Mark III, took place during the end of 1943 and the beginning of 1944, but by the time these were completed, there was no requirement for the unit and it was never put into production.[3]

Electric firing gears

Experience with electric firing gears on turrets fitted with ·303-inch Browning guns showed that they had many advantages over the pneumatic and hydraulic systems. With the introduction of the Mark V Hispano gun, which had no pneumatic cocking, there was not the same argument for the use of pneumatic firing systems in fixed gun fighters. As regards 20-mm. turrets, the Bristol design finally selected for development and production, was of the all electric type and electric firing control for the guns was considered essential, and a Magnavox sear release unit, developed by the United States Army Ordnance for the Hispano gun, was used on the first experimental turret. This unit was bulky and did not fit easily into the Mark II cradle; it also had a fairly high consumption of current. In anticipation of a requirement for electric firing control on the 20-mm. Hispano gun, Messrs. Dunlop's had already designed an electric sear release unit.

This unit was designed to work with the minimum current consumption and incorporated a small electric motor and flywheel, being similar in principle to the inertia engine starter. Various trials were carried out with this unit during 1942 and early in 1943; it worked reasonably well, but its bulk and position on the gun was such that it could not be used in any existing fixed gun or turret installation.

By the beginning of 1943, the provision of an electric firing system for the 20-mm. Hispano gun had become a matter of some urgency, and Messrs. Dunlop's agreed to drop their original scheme and proceed with a design that would be suitable for existing installations. The firm were still concentrating on producing a unit with minimum consumption of current, and in the new design this object was achieved; the first model having a consumption of six amperes at 24 volts as compared with ten amperes for the Magnavox unit. This low current consumption had been achieved at the expense of a mechanically complicated unit. It worked through a toggle action, and the gun sear was removed and replaced by a sear made in two sections that was part of the sear release unit. Owing to its method of operation this unit was known as the 'Trip' electric firing unit.

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[1] M.A.P. File R.A. 1042. [2] M.A.P. File R.A. 1032.
[3] M.A.P. File R.A. 1037.

Both splitting the sear in two sections, and making it part of the release unit was fundamentally unsound practice ; and the sear was one of the most highly stressed components in the gun and the new design weakened it and tended to throw some of the sear loads onto the release unit. The first trials took place in August 1943 at the Gun Test Unit, Cuffley. These trials were not very successful, the main trouble being the failure of the sear to arrest immediately the breech block on ' cease fire ' and so giving a ' runaway gun.' Trials of the unit were carried out both on the ground and in the air throughout 1943, and by the beginning of the next year the ' Trip ' electric unit had been developed to a point where it was considered fit for Service use and was put into production early in the year. By the middle of 1944, production models of the unit were being issued for use on prototype gun installations and from then until March 1945, continual failures were experienced with this unit and finally it was decided to cease production and withdraw it from service.

Concurrently with the development of the ' Trip ' electric firing unit, Messrs. Dunlop's had designed and developed an electric solenoid type of sear release unit. This was designed on more conventional lines than the ' Trip ' unit and in its original form had a current consumption of 10 amperes at 24 volts, and for this reason its development was on a lower priority than the ' Trip ' unit. Subsequently, the unit was modified so that although on opening fire it took 10 amperes, the steady current required to keep the sear in the disengaged position was only three amperes. This meant that although the peak current required was the same as the Magnavox, the total power consumed was considerably less. Trials with this unit, carried out during the latter half of 1944, showed it to be more reliable than its predecessor, and by the end of the year it was considered fit for Service use. With the failure of the ' Trip ' unit, it was decided to put the solenoid unit into production and it was introduced into the Service as the Maxiflux Electric Firing Unit. In spite of all the work done on electric firing units for the Hispano gun, no British made units were used in operations. The only operational aircraft to be fitted with electric firing guns was the Meteor which used the American Magnavox sear release unit.

For the 40-mm. Vickers ' S ' gun, the electric-pneumatic system was used ; a combined firing pin release and re-cocking unit being designed by Messrs. Dunlop ; other items of the installation being standard. The trials of this unit were carried out concurrently with the trials on the ' S ' gun, and the system was very satisfactory and gave no trouble in service.

PART II

GUNSIGHTS

CHAPTER 8

REFLECTOR GUNSIGHTS

Early history

Prior to the year 1925, gunsights in the Royal Air Force were of two types, *i.e.* the 'Ring and Bead' and the 'Aldis.' The former consisted of a metal ring, the diameter of which was based on a known target speed allowance, set at a predetermined distance from the gunner's eye. The bead, generally mounted in front of the ring, indicated to the gunner the direction in which his guns were pointing. The Aldis sight was a unit magnification telescopic sight for use with fixed guns and had the target speed allowance ring and sighting point incorporated in it. The bead on free guns was mounted on a vane which, actuated by the slip stream, automatically gave allowance for the gunner's own speed and was known as the Norman Vane Sight.

In 1923 a new sight known as the New Reflector gunsight was designed by Captain F. W. Hill of the Armament Research and Development Department (R.D. Arm), but it was not until two years later that development for Service use commenced. This sight was operated on a different principle from former sights in that the 'ring and bead' seen by the pilot or gunner was the image of a graticule reflected by the pilot's windscreen or a plate glass reflector. The graticule was illuminated electrically and the intensity could be varied by means of rheostat for day or night use. The gunner's sight was also fitted with a 'speed bar' to allow for the gunner's own speed and served the same purpose as the Norman Vane sight. Initial settings were made manually and automatic corrections were applied by spur gearing. A further refinement was a grey glass screen for use when sighting at a target with a bright background. Both fixed and free gunsights were developed simultaneously, and as they were basically identical, on the same lines. This account is mainly confined to the Pilot's type.

Advantages and disadvantages of the reflector sight

The advantages of the reflector sight were mainly :—

(*a*) Providing the user kept his eye approximately 10 inches away from the reflected graticule, the sight was efficient and imposed no limitations on the field of vision such as the rubber eyepiece on the Aldis sight.

(*b*) Once the sight had been correctly aligned, there was little risk of disturbing the accuracy by accidentally displacing component parts.

Inherent disadvantages existed, however, as follows :—

(*a*) Vibration of the reflector produced a blurred image of the graticule which at some speeds rendered the sight almost useless.

(*b*) The unpredictable light intensity of the target background rendered it difficult to find a satisfactory colour for the light screen or degree of brilliance of the illuminating medium.

As a result of trials, before introducing the sight into the Royal Air Force opinions were somewhat diverse, and a Fighter Area Report in October 1929 stated that the sight was inferior to both the ' Aldis ' and the ' Ring and Bead ' for day use, but superior for use at night.[1]

Production and development, 1937 to 1939

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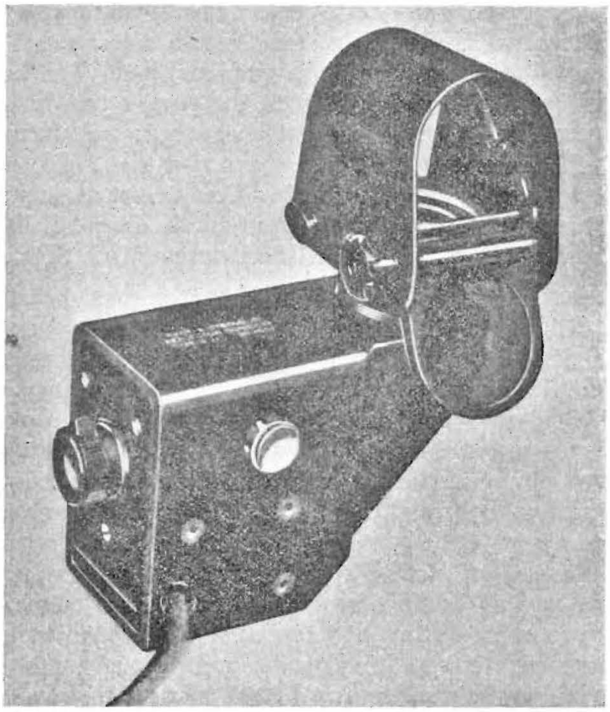


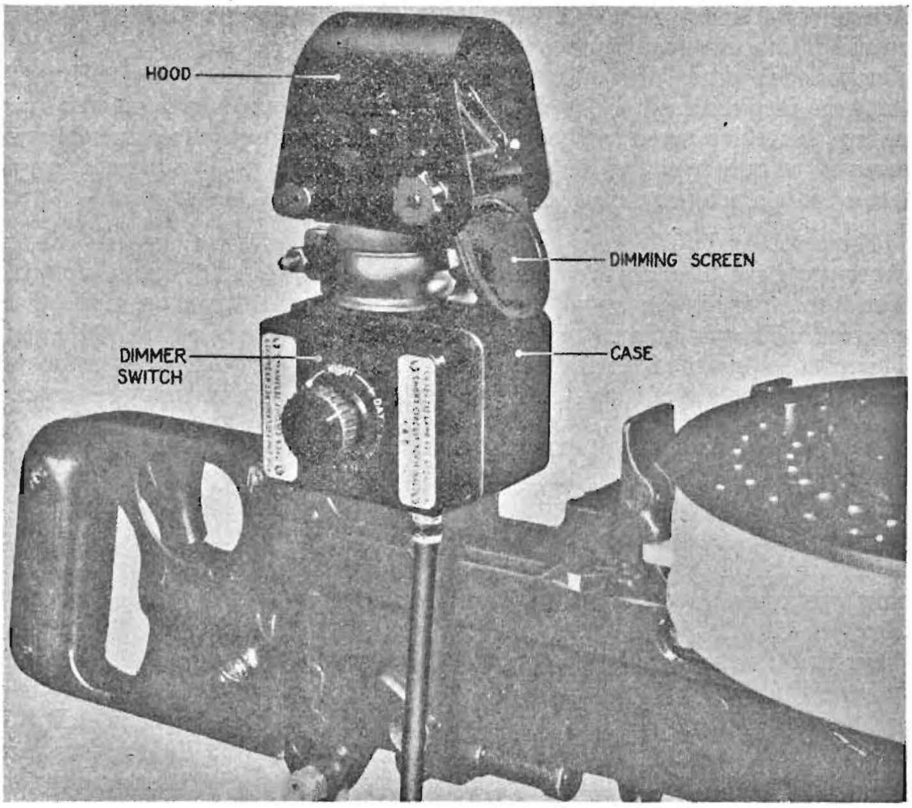
FREE GUN REFLECTOR SIGHT, MARK IA

G.M.1. and G.M.2 sights, and, apart from experiments with the intensity of illumination of the image, no further development took place until 1937, when trials were carried out on a new type of reflector screen. These trials were successful and an initial contract for 300 sights was placed with Barr and Stroud in January 1938. Additional trials on production sights were held using reflectors of clear and tinted glass, to test the effect of target visibility when the target was illuminated by searchlight beams, but there appeared to be little difference in visibility in the use of either screen. The original contract was increased in August 1938, to 1,600 pilot's sights with blue tinted ' Calorex ' screen, the new sight being known as the G.M.2 Mark II.

As the sight became increasingly efficient and more popular with the Service, the Goertz firm of Vienna embarked on a design of pilot's gunsight to provide

[1] A.M. File 798792/27.

an alternative source of supply to Barr and Stroud, Ltd., who could not meet the full Service requirements. The Goertz sight was known as the Mark III and consisted of a Barr and Stroud body with the firm's own optical system installed.[1] The firm were also testing a double filament lamp for use in the sight, and the reflector and lens system were undergoing temperature tests.[2] The optics of the sight showed little improvement over the British type and the double filament lamp did not satisfy the illumination requirements.



STARBOARD VIEW OF FREE GUN REFLECTOR SIGHT, MARK IIIA*,
MOUNTED ON VICKERS G.O. GUN

Development 1939–1945

On 18 March 1939, Air Chief Marshal Dowding, the Air Officer Commanding-in-Chief, Fighter Command, reporting on the tests of the reflector sight in his command, stated that the tinted Calorex screen was no advantage and, due to the numbers of inexperienced fighter pilots, could be a positive source of danger. He asked for clear glass to be used instead of tinted, and said that until the change was made, he had ordered all reflector sights to be replaced by ring and bead. It was suggested that a new lamp should be designed with the glass half-silvered to increase the illumination.

[1] A.M. File 753712/38. [2] A.M. File 646177/37.

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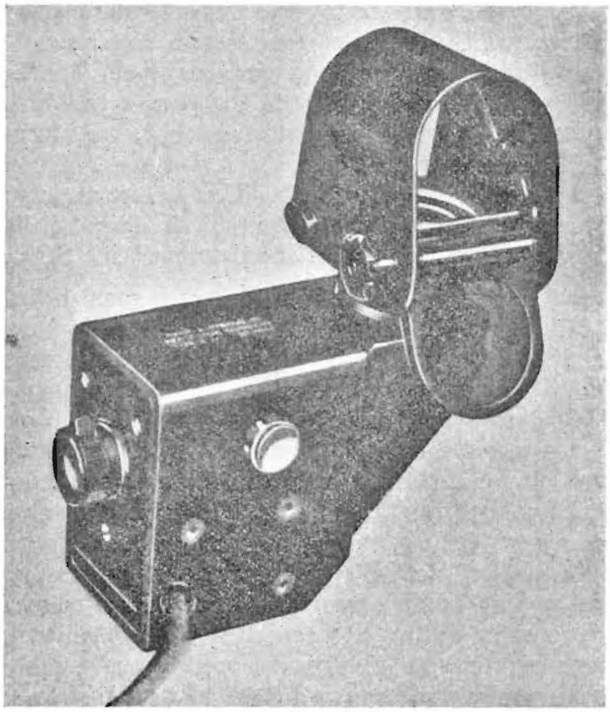

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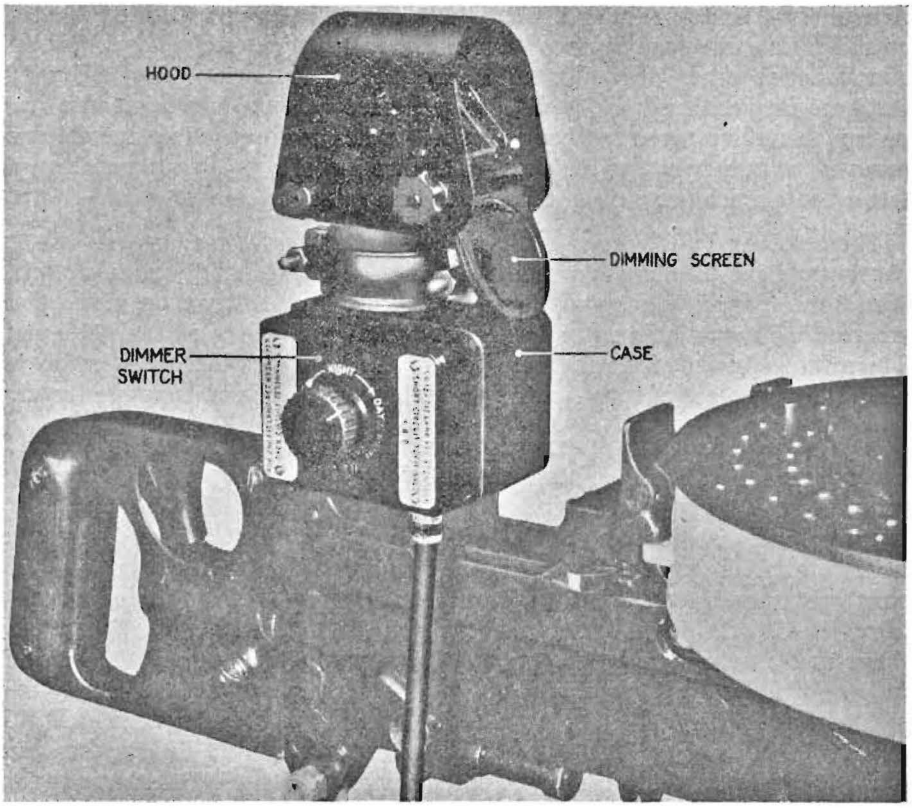

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[1] A.M. File 753712/38. [2] A.M. File 646177/37.

Meanwhile the use of the pilot's windscreen as a reflector became increasingly difficult. It was found that in the latest fighters—the Hurricane and Spitfire—the necessity arose for an entirely new windscreen before a clear image could be obtained. The angular setting of the windscreen, when used as a reflector, upset the streamline of the aircraft, and the glass, now ' bullet proof,' was extremely difficult to mould accurately.

In August 1939, Messrs. Barr and Stroud requested a ruling on the type of glass to be used in reflectors. They referred to a letter from the Director of Armament Development (D. Arm. D.) in which it was stated that reconsideration should be given to the use of super-protex glass, originally abandoned together with calorex, because of the tint. The firm pointed out that the type of glass used had been changed three times, being originally super-protex, then calorex and finally plate glass. Orders had been placed and deliveries received of both white plate glass and ordinary high quality plate glass, the latter being much more easily obtained than any of the others.

There was little difference in the ease of working of the types of glass, but super-protex required more care due to the ease with which it became scratched. Also super-protex was much more expensive than calorex or white plate, whereas ordinary high quality plate glass was slightly cheaper than white plate. The reflected image of the graticule was slightly brighter when super-protex was used, but the colour of super-protex was a disadvantage in viewing the target.

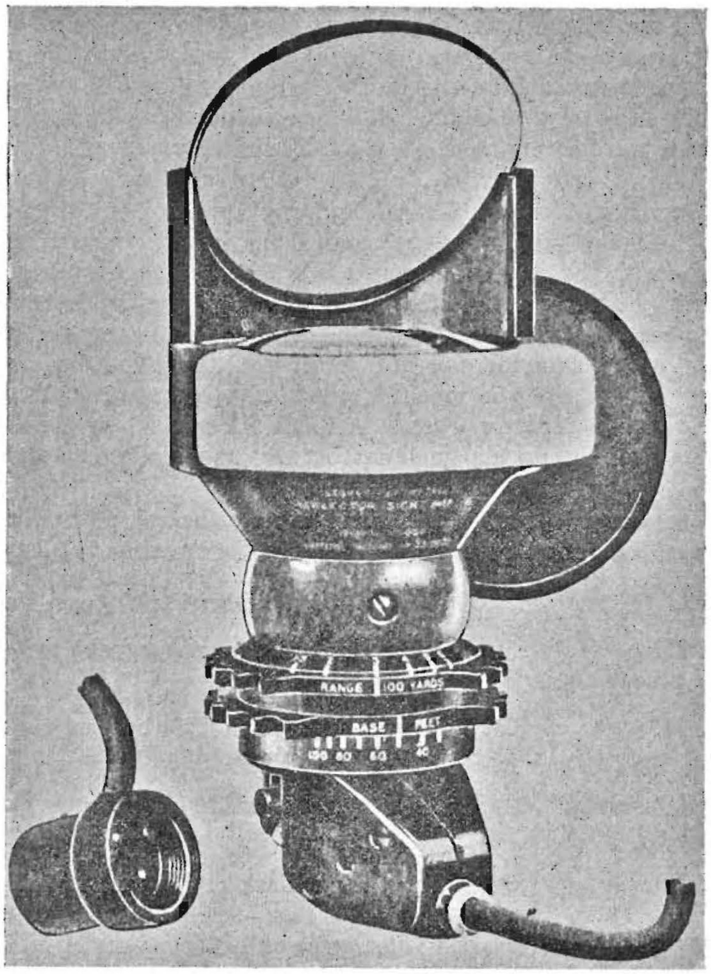
Just before the outbreak of war it was recommended that aircraft should be fitted with ring and bead sights as stand-by, due to the delay in construction and consequent delivery to the Service of G.M.2 sights. Alternatively some form of ' peep ' sight should be provided which would act as a stop-gap in the event of an aircraft being without means of sighting. The difficulty in providing ring sights was that the mounting position would be different in each type of aircraft, with the consequence that the aim of ' 4 degrees vision '[1] entailed a different diameter ring for each type. This standby sight would also be useful in case of failure of the reflector sight. The recommendation for fitting these sights, made by the Assistant Director of Research and Development (A.D.R.D. Arm.), did not meet with the approval of the A.O.C.-in-C. Fighter Command, who claimed that this fitting was not necessary when the reflector sight was fitted due, firstly to the low failure rate of the G.M.2 sight and secondly to the fact that the ring sight would produce an obstruction to vision both through the sight and from the pilot's normal flying position.[2] He did, however, realise the necessity for some form of standby sight and recommended the simple ' peep ' sight designed in his command. This consisted of a bead, off-set from its normal position, and a plate of thin sheet metal with a small hole drilled through it, affixed to the windscreen. He stated that with this type of sight, deflection firing would be impossible, but it would supply a direct sighting line for a stern attack, which was most used. Approval for fitting this type of sight was given by the Director of Operational Requirements (D.O.R.) in November 1939.

At that time the G.J.3 free gun reflector sight was found to vibrate excessively and in June 1940 the Director of Operational Requirements wrote to commands stating that approval had been given for the issue of the G.1 Prismatic sight as

[1] The angle from the pilot's eye to each side of the ring was four degrees.

[2] A.M. File S. 4956.

replacement. From that time onward development of the reflector sight continued, with alterations to the form of graticule. sun screens, degree of filament intensity and range of vision. The sight was well received in the Middle East Command, and this Command, in June 1942, suggested the inclusion of a 'turn and bank' indicator within the sight to give immediate indication of inadvertent side-slipping. This was not approved, however, on the grounds that side-slipping was largely self evident to the pilot, and the inclusion of such a device would not only increase the bulk and weight, but also obstruct the instruments in the cockpit. The suggestion from Coastal Command in August 1942, for a special graticule for ·5-inch guns was also ruled out, firstly because of production difficulties and secondly because the ring in the free gun sight only corresponded approximately to a crossing speed of 50 miles per hour.[1]



PILOT'S REFLECTOR GUNSIGHT, MARK II

[1] A.M. File C.S. 15792.

In September 1942, a 'Filter Diffuser Cell' for use at night was sent for trial. This cell was inserted into the sight between the lamp and graticule and gave a green image, uniform illumination with varying eye positions, and enabled tracer to be viewed throughout its flight path at night. This device was being tested by the Fighter Interception Unit (F.I.U.) by November 1942.

In the same month the American Air Force produced tinted goggles for use in conjunction with the night green filter, for further ease of observing red tracer. These goggles were not considered necessary by the R.A.F. because with the green filter alone, traces were clearly visible.

Early in 1943, due to the changes in cockpit layout and geometry, the need to use the windscreen as the reflector was increased for both day and night fighter use, but it was found that the graticule seen by the eye at any one point consisted of two images, one from each surface of the windscreen. When the windscreen was thick, as in the 'bullet-proof' type, one of the images was situated some distance from the central axis of the optical system and was apt to confuse the pilot. The filter diffuser was found to eliminate this second image, which was only apparent when a thick reflector was used.

Tests were carried out at the Air Fighting Development Unit (A.F.D.U.) with a modified pilot's reflector sight installed in a Spitfire aircraft. The standard G.M.2. sight with the reflector removed, was mounted one inch lower than the usual height. A reflector, consisting of an optically flat glass the same shape as the windscreen, was mounted one and a half inches nearer the pilot. This resulted in a far superior forward view, and the pilot did not have to concentrate on the sight so much as previously, as he was not conscious of looking through a reflector glass. A.F.D.U. remarked on the difficulty in cleaning the glass due to the small gap between the windscreen and reflector.[1]

It may be convenient at this juncture to note the types of pilot's reflector sights in use, the optical parts being similar in construction in all types.

Mark II	Oval reflector capable of taking sun screen.
Mark IIS	Rectangular reflector not capable of taking sun screen.
Mark II*	Similar to the Mark IIS but made to slightly different drawings.
Mark II* special ..	Similar to the Mark II* but reflector glass set at a different angle.
Mark IIL	Similar to the Mark II* but with a reflector glass adjustable for use with rocket projectiles, 40-mm. guns and other types of machine guns.

At that time, 7 April 1943, the Mark II sight was obsolescent and the possibility of standardising all the various types was being investigated.[2]

[1] A.M. File C.S. 17586. [2] A.M. File C.S. 15792.

In October 1943 the shortage of sights suitable for use with R.P., became so acute, and the use of the weapon so increasingly popular, that Fighter Command modified a standard Mark II sight to incorporate a tilting reflector glass. The Ministry of Aircraft Production gave approval for the modification and arrangements were made for the sights to be modified in quantity.

An American design sight, the N.9 reflector sight, was tested in April 1944. This was a modified version of the G.M.2 and although superior in some respects, did not exhibit sufficient additional advantages over the British version to warrant inclusion in the development programme.

CHAPTER 9

PRISMATIC GUNSIGHTS

General deficiencies of the G.M.2, fixed gun reflector sight had been noted during trials at Northolt and the Royal Aircraft Establishment (R.A.E.) during 1936. The main ones were inadequate illumination when used in daylight against a bright sky, and difficulty in finding and holding the graticule due to the limited field of view in which the graticule could be viewed. The optical characteristics of the sight were such that the image of the graticule could not be seen if the head was moved a few inches from the optical centre of the sight. It was agreed that the illumination could not be improved without risk of overheating, and it was wrong in principle to attempt to superimpose a highly illuminated image on very bright sky and cloud ; the correct method being to superimpose a black line graticule on a light background. By night, to provide an illuminated image against an almost invisible target would tend to reduce the visual acuity of the pilot. Difficulty would also be experienced in viewing the image against a target illuminated by a searchlight. Messrs. Goerz—the makers of the sight—were unable to improve the optical characteristics without increase in size, weight and cost, therefore the limitations in respect of the field of view were insurmountable.

Development 1936–1941

The Royal Aircraft Establishment suggested an alternative sight design, and in October 1936 had manufactured models of two types of sight—a type 'A' for fixed guns and type 'B' for free guns. These sights were similar to the Aldis sight in use, but by using prisms they were condensed in size so that they could be fitted inside the aircraft. The optical characteristics were superior to those of the Aldis sight, and a black line graticule was used which could be illuminated for use at night.

The chief disadvantage of the prismatic sight was that its loss of light was approximately 50 per cent ; a serious factor for night use. This disadvantage was balanced by the fact that both eyes could be used ; one through the sight and the other unobstructed. Service personnel who had used the reflector sight preferred the prismatic types because the graticule could be picked up and held more easily, and the black line graticule could be seen clearly by day.

At a conference on gunsight design, held at the R.A.E. on 12 October 1938, it was agreed that urgent tests should be carried out on the two types of prismatic sights with a view to their introduction as a replacement for reflector sights.[1] The type 'A' fixed gunsight, with suitable graticule, could be used in new turret installations as an observer's sight. The type 'B' free gunsight would be suitable for use on hand-held guns and turrets with limited installation space. Four type 'A' sights were ordered from Messrs. Ross, and tests were carried out at the R.A.E. in a Gladiator aircraft, to compare the prismatic sight with

[1] A.M. File S. 43505.

the reflector sight. Different graticules were to be fitted to the sights in order to select the most suitable for day and night use.[1] The sights used on the trials did not incorporate adjustable range indicators, but the graticules carried a fixed range indicator giving the same effect, and the adjustable range indicators were to be a feature of the production sights.[2] Four type 'B' sights were also to be made for trial, in the sighting of free guns. These sights incorporated different types of graticule and had an adjustment for gravity drop.

The aim when designing the graticules was to reduce the number of lines, as it was considered that a complicated graticule would confuse the gunner. The following features were embodied in the graticule for day use:—

- (*a*) A 50 m.p.h. deflection ring in accordance with the relative speed principle.
- (*b*) Two horizontal bars for range estimation should this be required.
- (*c*) A fixed centre spot on three of the graticules for no allowance firing; the fourth had no centre spot.

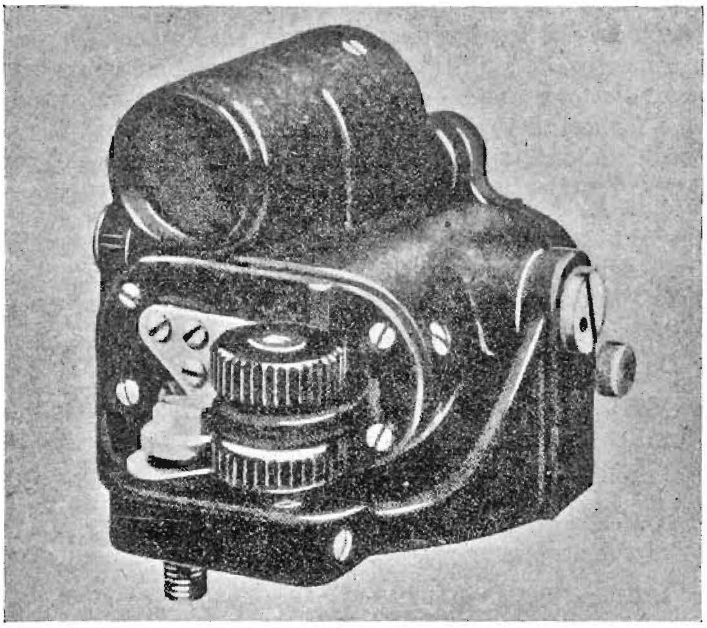
For night use, the graticules were the same as for day use, but they were only partly illuminated as it was assumed that the minimum of illuminated lines was desirable for night conditions.

During trials at Northolt in April 1939, one aspect of the illuminated sight, which had not been stressed previously, was brought forward. The life of the electric bulb used for illumination could not be determined within wide limits and failure would leave the pilot without adequate means of sighting at night, and an attempt was made to utilise other means of illumination free from the limitations of filament lamps. Spare bulbs for the sight were carried in the aircraft, but there was the possibility of losing the target during bulb changing. It was agreed by the greater number of pilots who carried out the tests, that with an illuminated graticule, it was possible under night conditions, to see this graticule against a background as long as detail in the background could be distinguished; or if the pilot could see the target aircraft, he could also see the graticule. The unilluminated graticule was found to be satisfactory under normal night conditions, but when the target aircraft was illuminated by a searchlight, something more was required, since the bright object made it impossible to see the graticule against the background.

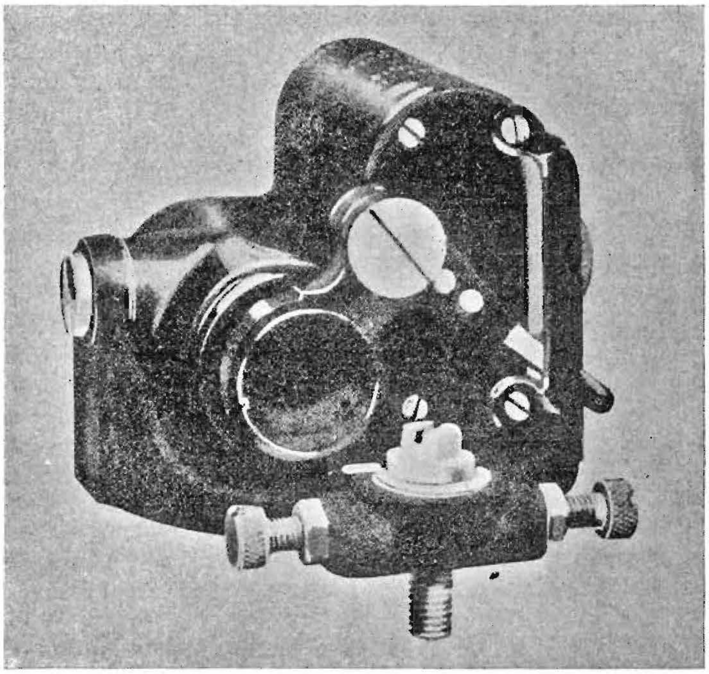
To overcome this difficulty, two blobs of luminous paint were placed on the range bars, and these spots were found to be sufficiently bright to enable the pilot to take aim by centering the illuminated object between them. Under conditions where the luminous spots were not required, they were withdrawn to the edge of the field by turning the span indicator dial in such a manner as to increase the gap between the range bars to a maximum. After extensive service trials the design of the type 'A' pilot's sight was submitted for approval in November 1939. About this time the type letters were changed from 'A' and 'B' to 'P' and 'G' to indicate 'Pilot' and 'Gunner.'

Trials continued during the following months, and in March 1940, after flight tests in a Spitfire, it was considered that the prismatic sight was a retrograde step. The bulk of the sight was in a direct line of the pilot's vision through

[1] A.M. File S. 39645. [2] A.M. File S. 48189.



Prismatic Gunsight, Type G.1.
(Viewed from the Eye Lens End)



Prismatic Gunsight, Type G.1.
(Viewed from the Object Glass End)

the starboard side of the windscreen, and as the side panels were very extensively used during normal flying, there was no advantage in the prismatic sight which justified the serious interference with the pilot's view which it caused.

In April the Royal Aircraft Establishment suggested that the sight should be re-designed in similiar form to the P.1 but to have prisms of reduced height, due to the possibility of the shortage of glass in case of prolonged war, but the Director of Armament Development considered that alteration of design would cause an undesirable diversion of effort as it was anticipated that the next type of prismatic sight would be a gyroscopic sight, so the idea was abandoned.[1] Manufacture of the sight and trial installations ceased in June 1941, as it was agreed that the P.1 sight did not meet Air Staff requirements.[2]

[1] A.M. File S. 46624/1. [2] A.M. File S. 48199.

CHAPTER 10

PREDICTOR GUNSIGHTS

The question of using large calibre guns in aircraft was under investigation during 1936 as it was considered that one hit with a shell of approximately two pounds weight would destroy an aircraft. It would also be possible to engage the enemy at much greater range, but, in order to be able to hit the target, some means of range estimation would be required. The Air Ministry were particularly interested in the application of large calibre weapons to turrets and the turret firm of Nash and Thompson were asked for their views on the possibility of fitting a range finder or range indicator in the turrets being designed, so that the gunner would be able to apply the necessary sighting allowances. The factors to be taken into account were :—

(*a*) Range.

(*b*) Ballistics.

(*c*) Air resistance.

(*d*) Altitude.

(*e*) Own speed.

(*f*) Relative speed.

It was considered that the control to embody the above could consist of hand setting for altitude and own speed, which could probably be pre-determined and quite possibly would not require changing during the actual engagement of the enemy.[1]

Two methods of obtaining relative speed allowance were investigated in August 1938 :—

(*a*) By two pairs of governors, driven through free wheels, each pair having one right- and one left-handed drive. Movement of the gun in any composite direction would start up one governor for the horizontal element and one for the vertical element of movement. The rate of movement of the governors would apply corrections through a 'follow up' mechanism. These corrections would be modified by range.

(*b*) By the use of two hydraulic pumps with a reversible flow. The rate of flow caused a corresponding movement of a spring centralised piston, which movement would uncover axially cut slots or ports to a degree proportionate to the rate of flow. The difficulty was to obtain a fluid with sufficiently small variation of viscosity, at different temperatures, to obtain an accurate correction. Movement of the piston was modified by the range.

In both cases range was to be determined by a range finder.

[1] A.M. File S. 43255.

Design of a simple form of predictor sight was suggested by a technical officer of the Air Fighting Development Unit (A.F.D.U.) in October 1938. The basic arguments from which the idea developed were[1] :—

(*a*) That it was highly desirable for a fighter to be able to deliver accurate fire whilst carrying out a manoeuvre which made accurate return of fire from the enemy difficult.

(*b*) That when firing under the above conditions was possible, the predominant sighting allowance which the fighter had to make was for crossing speed, and that if this part of the allowance could be made automatically with reasonable accuracy, gravity and trial allowance could probably be covered by group size.

On the outbreak of the Second World War, the methods of sighting guns in the air was in need of urgent attention. Five aspects were considered to be of sufficient importance to be treated with the highest priority[2] :—

(*a*) The control of bullet dispersion to cover aiming errors with particular reference to new types of aeroplanes coming into the Service.

(*b*) The use of standard or special tracer bullets as an aid to aiming allowance.

(*c*) The development of the 'Turn Indicator' sight for fixed gun fighters.

(*d*) The development, for the turret gun, of a simple predictor sight, without optical range finder, and based on the 'Turn Indicator' method of allowing for relative velocity.

(*e*) The development of the Royal Aircraft Establishment (R.A.E.) shutter sight for use with tracer bullets.

Bullet dispersion

It was considered that the bullets from machine guns, whether of ·303-inch or 20-mm. calibre, should be dispersed about the mean point of aim sufficiently to cover the probable errors of aim, which in the case of air gunnery were mainly from inaccurate estimation of the relative velocity of the target across the line of fire. It was impossible to predict what war experience would show, but on the information then available, it was considered that all installations, whether fixed or moving guns, should be capable of adjustment so as to disperse the bullets in a cone of about two degrees. This did not imply that a two degree cone would always be desirable, but it should be possible to adjust the guns to give any desired dispersion to this amount.

Tracer bullets

Some form of tracer was considered necessary in the gun armament of bombers, but whether it should be used by fixed-gun fighters was open to doubt, and could only be decided by war experience. In the fixed gun fighter the pilot made his allowance in accordance with the attitude of the target and this was less difficult than the corresponding problem for the movable gun where the allowance depended on the direction of fire relative to the gunner's aeroplane as well as upon the attitude of the target.

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[1] A.M. File S. 47333. [2] A.M. File S. 1953.

Experiments on a new form of tracer which was visible only between assigned ranges had been in progress at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) for some time, and had been held up by difficulties which the manufacturer of the ammunition had been experiencing in sufficiently suppressing the trace at short ranges. Tracer, particularly of this new type, would provide the most hopeful means of quickly increasing accuracy of free guns.

Turn-indicator sight for fixed guns

The first great improvement in accuracy of fire from fixed-gun fighters was expected from the use of a predictor sight under development at the Royal Aircraft Establishment (R.A.E.). It contained a form of gyro-turn indicator which gave the sight-line an angular displacement proportional to the angular velocity of the gun. When correctly adjusted for range and air density, this sight, so long as it was held on the target, was capable of giving correct allowance in all circumstances.[1]

Simplified predictor sight for turret guns

Three firms were working on designs of predictor sights which involved optical range-finders, and accuracy depended on the aeroplane flying a steady course.[2] There were grave objections to accepting either of these limitations in schemes intended for the defence of bombers, unless the bomber could be equipped with secondary armament to deal with close range attacks.

In air fighting the enemy could, at that time, approach from a range at which he was safe from any form of fire to close quarters in a very short time. It was therefore dangerous to adopt any scheme for accurate long range defensive fire if it interfered with the power of dealing with close range attack, or with the gunner's view over a wide angle. It was considered that work on these types of sights should be directed at the far distant future and that efforts should be concentrated on producing a predictor in which the gunner looked through open sights, such as the standard reflector or prismatic sights, with the widest possible view all round, and in which the accuracy was not entirely destroyed when defensive manoeuvres were undertaken.

Automatic adjustment for relative speed should therefore be operated in a similar way to the fixed gun sight, by turn indicators, rather than, as in sights at that time being designed by firms, from the rate of movement of the guns or turret relative to the aeroplane. Range should be judged by comparison of target size with rings or marks on the sight graticule, and range adjustment operated without removing the eye from the target.[1]

It was assumed that tracer ammunition would always be used with the sight. The object was to show the gunner in which direction to sweep the aim to cover possible errors in the automatic allowance. The trace, with a correctly harmonised predictor, intersected the sighting line at the range for which it was adjusted, and if the target was not at this range the trace crossed the line either between the target and gunner or beyond the target. The apparent direction of the trace on the graticule sight, as it passed the central sighting line, showed the direction in which search should be made to cover these errors.

[1] A.M. File S. 1953. [2] A.M. File S. 47090.

The shutter sight

A method of viewing tracer ammunition through a sight containing a shutter was suggested by the Royal Aircraft Establishment and preliminary ground trials were carried out. The shutter was closed when the gun was fired and opened automatically after a specified time. The principle was similar to that of delayed flash tracer; that is to get an indication of the range of a selected part of the trace; in this instance from the apparent start of the trace. The advantages of the idea were that the range of the apparent beginning of the trace could be altered at will by the gunner and that it did not call for special ammunition. The method was, however, not easily applied for the machine gun, but was considered as a possible solution of the sighting problems for heavy ammunition fired in separate shots which could be watched to the target.

Development of the gyroscopic predictor gunsight

The development of a predictor gunsight primarily for use in single seater fighters, was discussed at a meeting held at a civilian firm of optical instrument manufacturers on 9 March 1939. A general arrangement sketch had been produced by the Royal Aircraft Establishment, and it was agreed that this should form the initial basis of design, after certain modifications were incorporated. As far as practicable the first experimental model was to be built from standard parts already used by the firm for other purposes, and that certain design data relating to oil pressures in the hydraulic control system were to be determined from measurements made on the experimental model during initial development. Two separate units were to be made in order to expedite later experimental work. The representative of the Director of Armament Development (D. Arm. D.) who attended the meeting recommended that the gyroscopic unit should be used to control a prismatic gunsight of the latest type. Methods of effecting the control were suggested but it was necessary to give further consideration to this point before details of design were given to the firm.[1] Several difficulties mainly with the hydraulic system appeared early in the design of the sight, indicating lengthy development work.

In view of the urgency of the requirement, the R.A.E. decided to use an air driven gyro, operating at 10 lb. per square inch pressure from the exhaust of the flying panel suction pump. This unit was to be coupled to a pilot's prismatic sight having a moving wire graticule operated by metallic bellows. A double oil dashpot was fitted to the graticule operating mechanism to suppress vibration of the graticule, but this was found to be effective only between certain engine speeds. It was also necessary, on theoretical grounds to introduce lag into the operation of the graticule, so that the allowance was proportional to the rate of turn of the sighting line instead of rate of turn of the aircraft. During early flight tests at R.A.E., the pilots found no difficulty in maintaining the sight on the target during avoiding action.

Flight trials were carried out at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) between 23 October and 13 November 1939, in a Hurricane aircraft[2]; the gyroscope mechanism being mounted at a different

[1] A.M. File S. 47333.

[2] A. & A.E.E. Report BD/GRO/14 dated 3 April 1940.

point in the aeroplane and controlled the sight pneumatically. The gyroscopic correction was applied to the sight line by moving the graticule in the focal plane of the sight, and adjustable control of lag between gyroscope and sight was provided in the connecting pipe lines. The sight was set for a time of flight of 0·5 seconds corresponding to about 400 yards range.

Cine gun trials were carried out with the object of testing the pilot's ability to use the sight, and the correct functioning of the sight. Pilots found no difficulty in bringing the sight to bear, and in holding it on the target. Also there was no difficulty in making large deflection attacks provided that the controls were used smoothly. In any of the attacks, sudden control movements prevented the sight being brought easily on to the target. Spiral avoiding action was more difficult to follow, and it was difficult to get the sight on except at the top of the cycle.

Firing trials were carried out to make a direct check on the range setting of the sight. The sight and guns were harmonised at 400 yards and the inner gun of each wing was loaded with tracer ammunition which burnt up to a range of about 400 yards. It was considered that if the sight was working correctly, the tracer would always end at the centre of the graticule no matter how the aircraft was moving provided that the range setting was 400 yards. The trial was carried out for turns up to rate 3. Results were good for rate 1 turns, but during earlier handling the sight had been overstrained and put out of adjustment so that it failed to work correctly at the higher rates of turn.

Pilots stated that the sight was pleasant to use and not difficult to handle provided the control movements were smooth and no attempt made to snatch the sight onto the target. Vibration of the graticule was very noticeable and although it did not make it impossible to use the sight, it would have to be reduced before the sight was suitable for general use. It was easy to use both eyes with the sight and there was no obstruction to view.[1]

As the sight had proved satisfactory during the trials, the Royal Aircraft Establishment, in October 1939, proceeded with the design of a sight and gyroscope contained in one unit. It was to be no bigger than the G.M.2 reflector sight, would simplify installation and should give immunity from aircraft vibration as the graticule would be coupled to the gyro. It would be possible to make sensitivity independent of gyro speed and would indicate the rate of turn of the sighting line directly without providing for control of lag in the pipelines. It was considered that this arrangement could be used in a turret since the whole sight could be moved relative to the gun to give corrections for trail and gravity.[2]

The Mark I gyro gunsight

The first type of gyro sight to be developed, known as the Type 6 Mechanism, was essentially a turret sight rather than a pilot's sight for the following reasons :—

(*a*) It incorporated the small prismatic free-gunsight optics (G.1) which was barely large enough for turrets and was considered too small for normal use by pilots.

[1] A.M. File S. 47333. [2] A.M. File S. 43368.

(*b*) The aiming allowance for fixed guns depends only on the speed and attitude of the enemy aircraft. With free guns, however, own speed and direction, and trail of the bullets due to cross-wind, had also to be taken into account. The gyro sight, which eliminated all estimation, except that of range, from both aiming problems, was therefore of much greater value for free guns than for fixed.

(*c*) In turrets, there was no rational alternative to 'following' the targets and estimating the range. For fixed guns, however, range need not be a first order quantity in the aiming allowance, nor was it absolutely essential that only curve of pursuit attacks should be used. It was seldom possible to obtain lethal hitting density except by holding the target in the sight during a burst, but there were many occasions in combat when only short bursts were possible with the target flying quickly through the sights. For such attacks, the gyro sight might be a cause of confusion.

The design of the turret gyro sight was nearly completed in June 1940, and evidence was accumulating that ·303-inch ammunition to which we were committed for some time to come, was becoming more and more ineffective for destroying armoured enemy bombers from astern. For that reason a gyro sight to assist pilots in deflection shooting became an urgent requirement.

There were three possibilities at that time of producing a pilot's sight quickly :—

(*a*) To scale up the turret sight to similar dimensions to the pilot's reflector sight (P.1), or another large prismatic sight of new design. This had the advantage of using known and proven technical principles, but the sight would be very large and difficulties in installation were foreseen ; also production of a large prismatic sight in quantities would be a difficult manufacturing problem.

(*b*) A reflector gyro sight could be designed for pilot's use, but there would be a long development period which ruled out this solution.

(*c*) The turret sight, with minor modifications, could be used. The anti-vibration mounting essential in a turret sight would be redundant, and the overall bulk could therefore be slightly reduced.

Tests at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) had shown that the G.1 sight, though far from ideal, could, in practice, be used by pilots. This third course was eventually adopted and the basic turret sight was produced in three versions, the Marks IA and IB for pilot's use on 12 volt and 24 volt circuits respectively, and the Mark IC for use in turrets.

Development of the sight continued during the following year, difficulty in production being experienced in the manufacture of the universal mounting for the gyroscope mirror. Unless great accuracy was obtained in this part, the sight was inaccurate and consequently useless. Two types of sight (Marks IA and IC) were introduced into the Service during 1941 ; but were only used to a limited extent.

Design of the Mark II gyro sight

The Royal Aircraft Establishment (R.A.E.) proceeded with a design to overcome the disadvantages and difficulties encountered with the Mark I sight. The new design contained two independent optical systems, each of which produced an illuminated image seen by the gunner in the reflector. The two graticules were viewed by separate eyes and appeared superimposed at long ranges.[1] The left-hand optical system had a fixed graticule marked with a small ring and cross, which was reflected by a fixed mirror at the back of the sight, on to an inclined front mirror and up through the left-hand lens to the reflector. This fixed cross indicated the line of aim of the guns.

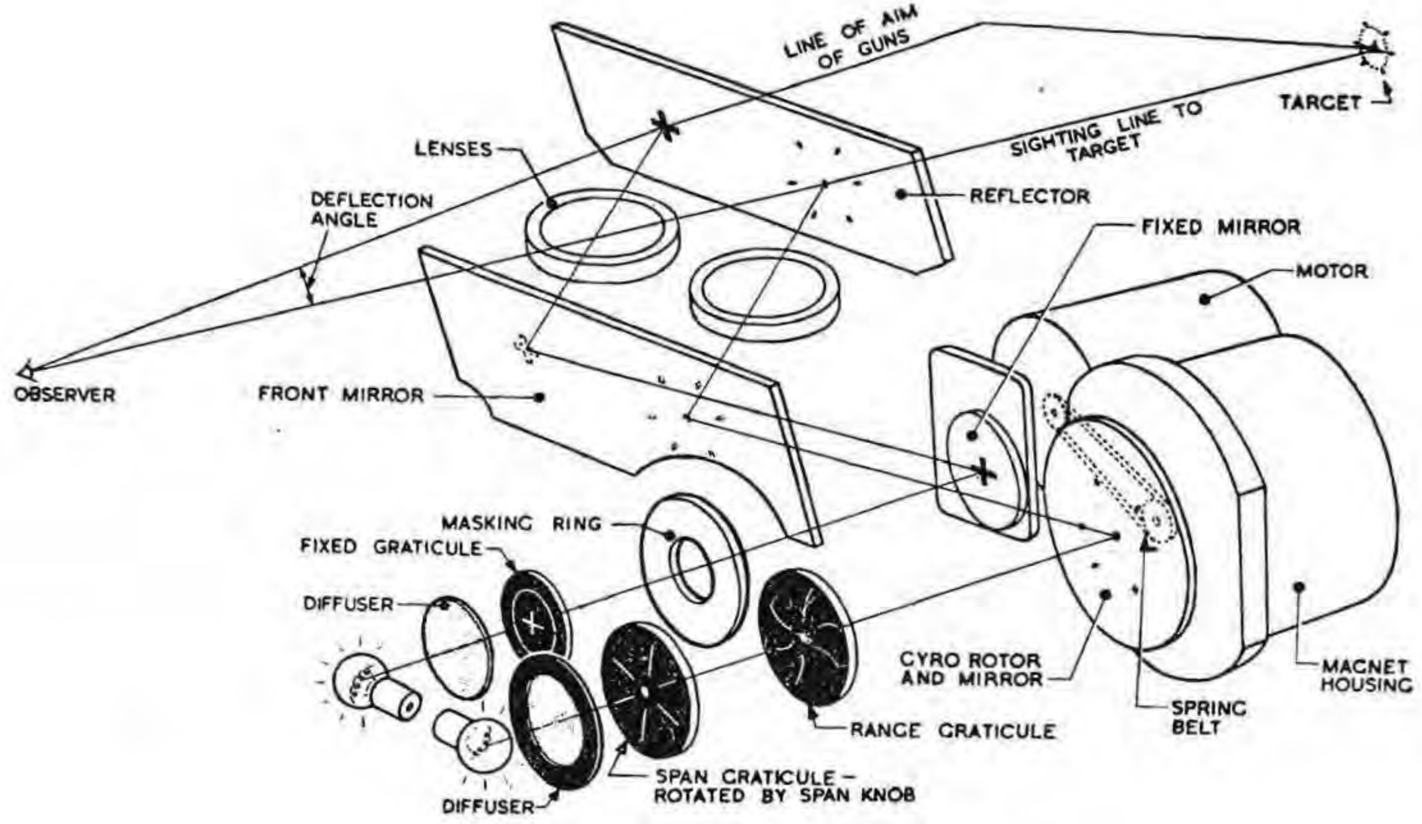
The right-hand optical system had two superimposed graticules and produced a pattern of six diamonds with a central bead. This pattern was reflected by a mirror at the back of the sight, on to the inclined front mirror and up through the right-hand lens to the reflector. The mirror was not fixed, but deflected in various directions under the influence of an electrically driven gyro to which it was attached. Thus the position of the six pointed pattern, seen by the gunner in the reflector, was determined by the gyro. Provided the gunner operated the controls correctly, this pattern, known as the moving graticule, indicated where the target must be placed and held to make the correct sighting allowance.

The reason for two superimposed graticules in the right-hand optical system was as follows. To enable the sight to compute the sighting allowance correctly, the range of the target at any instant must be known ; the two superimposed graticules formed a simple type of range finder. The span graticule had six radial lines and a central bead, and the other, the range graticule, six curved lines and a central head. If one of these graticules was rotated relative to the other, the radius of the six-diamond circle, forming the moving graticule, would increase or decrease. The span graticule was positioned rotationally by a control on which the gunner set the actual size of the target, and the range graticule was rotated through a system of pulleys and cables from the gunner's range pedals. The gunner operated these pedals to vary the size of the moving graticule so as to keep the target spanned by the diamonds The relative rotational position of the two graticules was measured by an external control unit called the range control, which fed the necessary range data into the electrical circuit of the sight.

The gyro unit controlled the moving mirror in the sight in such a way that the moving graticule seen by the gunner in the reflector was displaced from the fixed graticule by the appropriate deflection angle. The gyro carried an electrically conducting but non-magnetic dome, and if a magnet was placed near the dome, the spin axis of the gyro and dome would precess towards the magnetic axis until it became aligned with it.[2] Further, if the magnetic axis was turned at a steady rate, the spin axis of the gyro and dome would 'follow' the magnetic axis, but would lag behind it by an angle which depended on the

[1] A.M. File H.S. 68835.

[2] The reason for this was that strong eddy currents were produced in the conducting dome, and these eddy currents produced their own magnetic field. This magnetic field reacted with that of the magnet in such a way as to cause precession of the gyro axis towards the magnetic axis.



GYRO GUNSIGHT SIGHTING HEAD OPTICAL SYSTEM rate of turn of the magnets axis and the strength of the magnet. Thus the moving mirror and hence the image of the moving graticule became displaced from its central position by an amount depending on the rate of turn.

The gyro housing contained the range coils which were fed with electric currents from the range control, proportional to the time of flight of the bullet to the target. The housing also contained the trail coils which precessed the dome by the appropriate amount.

The object of the gunner was to bring the sight on to the enemy aircraft at 800 yards with the inside edge of the diamonds fitting its wing span, and, as the range closed to keep the diamonds on the wing tips by depressing the right-hand foot pedal. The range control in the sight automatically allowed the correct deflection and gravity drop; the gunner's own speed and height were fed into the sight after being pre-set by the gunner on two dials.

A four way selector switch was fitted which could be used as follows:—

(*a*) 'Fixed'—The fixed ring only was illuminated. This ring was used for harmonising and was available in the event of the moving graticule becoming unserviceable.

(*b*) 'Fixed and Gyro'—The fixed ring and gyro controlled radial diamonds were both illuminated. When the gunner was using both eyes, the fixed ring and radial spots appeared superimposed. When the right foot pedal was pressed down (*i.e.* short range—200 yards) the centre spots of both rings would be identical. When the left foot was down—800 yards—the gyro controlled radial diamonds would be below the fixed ring owing to the automatic allowance for gravity drop.

(*c*) 'Gyro Day'—Only the gyro controlled diamonds were illuminated. This setting was normally used for all day operations.

(*d*) 'Gyro Night'—Again only the gyro controlled diamonds were illuminated, but the deflection and gravity drop was automatically set for 150 yards range irrespective of the position of the foot pedals. It was possible to expand or contract the radial spots with the foot pedals, but this was only for the gunner's individual preference at night.

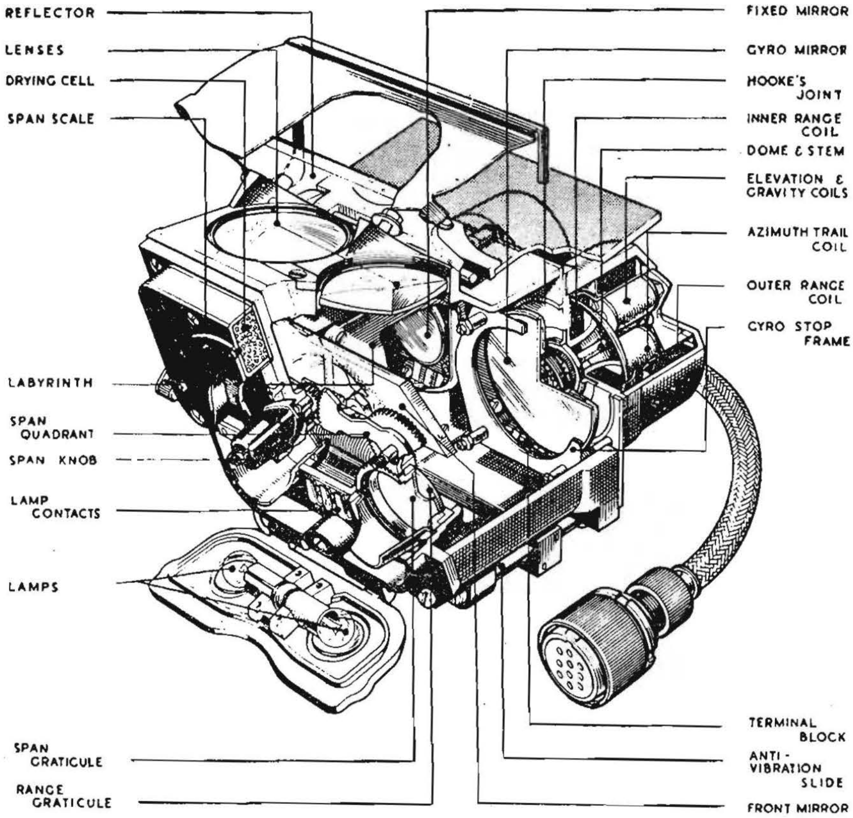
The first type designed was the Mark IIC for use in bomber gun turrets and air trials were carried out at the Air Fighting Development Unit (A.F.D.U.) between 24 August and 21 September 1943 in a Lancaster aircraft.[1] Day trials were brief only, as the Gunnery Research Unit (G.R.U.) had already carried out a comprehensive series of trials. The gunners found it was easy to keep the moving graticule on the target, but that accurate ranging with the foot pedals required about two hours practice. There was also a definite technique for swinging the sight on to the fighter; the right foot should be kept down so that the gyro was closely controlled, as if for short range with corresponding little deflection. If a rapid turret movement was made with the left foot down—as if in long range—the deflection was naturally very great and the moving graticule would hit the stops causing a momentary vibration of the gyro controlled mirror. When the gunner's aircraft was carrying out standard combat manoeuvres of steep diving and corkscrew, he could still maintain accurate fire.

[1] A.M. File S. 96820.

Night trials were carried out to assess the value of the sight under varying conditions of moonlight and darkness. On dark nights without moon, the 'gyro night' setting would be used except when in an area illuminated by fighter flares or target flares. In moonlight, however, the 'gyro day' setting could be used with reasonable efficiency. Since, however, the average night combat at that time rarely took place at a range of more than 400 yards, it was obviously likely to help the gunner if the foot pedal was restricted in its travel to correspond to a range of 400 yards instead of the usual 800 yards. In general the sight could be used with so much more accuracy in conditions of bright moonlight than in darkness, that bombers would be able to achieve greater success with fewer losses if major operations took place in the moon period.[1]

As a result of extensive trials it was found that the gyro sight could be used with exceptional accuracy against all fighter attacks in daylight and could be used accurately throughout standard manoeuvres. The sight was considered to be the complete answer to gunnery problems, and if a reasonable standard of training could be achieved, adequately armed bombers would be perfectly capable of defending themselves against fighters in daylight operations.

During the trials of the Mark IIC sight the design of a pilot's type of sight was commenced. The pilot's type, for use in front gun fighter aircraft was



GYRO GUNSIGHT

[1] A.F.D.U. Report No. 98.

similar to the free gun type except that it had a larger lens system to provide greater eye freedom. Service trials with this sight—the Mark IIA—showed such promise that production development was started immediately, but as it was evident that supplies would not be available for some time, and since the Mark IIC had by that time reached the early production stage, it was suggested by R.A.E., that a trial of the Mark IIC in fighter aircraft should be made. An experimental installation indicated that the Mark IIC unit was acceptable in a fighter aircraft, and the Mark IID was developed. This was formed by minor modifications to the Mark IIC such as to allow for good installation in a fighter and to obtain a ballistic solution suitable for this type of aircraft.[1]

Trials were carried out in a Spitfire aircraft, and it was found that the handling was the same as with the pilot's gyro gunsight (G.G.S.) Mark IIA. The installation layout was good, but the plain reflector glass fitted to the sight did not give sufficient graticule brightness, and the sun screen was too dense for ordinary use. It was suggested that a lightly silvered glass should be substituted for the plain glass. The method of harmonisation was good, but the bracket attachment to the aircraft was too flimsy and would have to be strengthened to avoid deflection under heavy 'g' and vibration, and to keep the sight correctly harmonised for long periods between inspection. The sight installation obscured a fairly large amount of the instrument panel, but this could be improved by re-positioning certain components. No trouble was experienced when viewing fixed and moving graticules by different eyes.[2] Production of the sight was commenced and supplies were reaching the Service late in 1943.

Predictor sight for use with rocket projectiles (R.P.)

A modified type of Mark IID sight was introduced into the Service during 1945. This was similar to the standard Mark IID except that it was designed to cater for the longer time of flight of the rocket projectile. The preliminary run-up to the target for R.P. attacks was much longer than with gun sighting and required extensive manoeuvring of the aircraft. During this preliminary run-up period, the image of the moving graticule wandered from the central harmonised position. Consequently during the initial stages of an attack, the pilot was unable to bring his sight to bear on the target, with any degree of accuracy, until sufficient time had elapsed to permit the moving graticule system to recover from the effects of a turn, and resume a central harmonised position.

To eliminate this time lag, it was necessary to apply a restricting influence on the gyro to prevent wander of the moving graticule during approach manoeuvres, but once on a course towards the target the constraint on the gyro was released. This 'caging' or restricting the movement of the moving graticule during the run-up period, ensured that the sight was in a harmonised position and was instantly available for attack sighting, regardless of previous manoeuvres. Caging was achieved by feeding into the range coils of the sight, an electrical current strong enough to eliminate wander when the caging circuit was made. When the caging circuit was broken, the electrical supply to the range coils was normal.

[1] A.M. File S. 21640 Part I. [2] G.R.U. Report GRU/C.315.

CHAPTER 11

PERISCOPIC SIGHTS

To provide protection against stern attacks from below in bomber aircraft, it was necessary to mount guns in the front of the aircraft to fire to the rear. This meant that the gunner could not take a direct line of sight on the attacking aircraft and to provide a method of indirect sighting, the periscope sight was designed.

Type 'A' sight

The first type was used in the Fraser-Nash 54A and 60A under defence turrets which were fitted with twin Browning guns. The turret was hand-operated, and the guns could be depressed and traversed. The sight, known as the Type 'A,' consisted of a unit magnification telescope having a mirror, inclined at 45 degrees to its optical axis, at one end. The telescope was fitted into the control column of the turret, and at the lower end of the control column, half way between the two guns, was a second mirror inclined at 45 degrees. Thus the gunner could look into the top mirror and see along a line half way between the guns. The control column, which was perpendicular to the gun barrel, had two handles, and movement of the control column in a vertical plane, away from or towards the gunner, caused depression and elevation of the guns, whilst rotation traversed the guns. The original experiments were carried out with an Aldis sight by Nash & Thompson, the turret manufacturers, as a private venture.

The graticule of the sight consisted of a circle of 4 degrees diameter with a centre dot. A pair of parallel lines about the centre dot enabled the sight to be used for taking drift, and two short lines, perpendicular to the parallel lines, were placed symmetrically about the centre dot for ground speed measurements.[1] The first six production sights were tested in March 1941, and it was found that the field of view in each was only 17 degrees; the specification requirement was 20 degrees. These sights were accepted as a temporary measure, but the full 20 degrees was a definite requirement and modification in the design to include this field was necessary. This modification took place after the first 1,000 sights had been made; the unmodified sights being known as the Type 'A,' Mark I.[2]

The early sights with a 20 degrees field, were sealed against ingress of moisture by using a wax compound, and the bottleneck in production was the assembly, sealing and desiccation. In view of this the sight was re-designed to use screwed lens cells with retaining rings and tests on this type of sealing proved entirely successful. The early sights were known as the Mark II and the later type the Mark II*.

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[1] M.A.P. File R.A. 1860. [2] M.A.P. File R.A. 1694 Part I.

Plastic materials for periscopic sights

When the requisition was placed for the under defence turret sight in November 1940, the Director of Instrument Production (D.Inst.P.) considered that the production of a sufficient quantity of periscopic sights would probably prove to be a bottle-neck. A representative of the Operational Requirements branch of the Air Ministry visited the Nash & Thompson works and was shown a sight made with perspex and paxolin which was stated by the manufacturers to be a cheap and simple production job. It was stated that the sight would probably be unsuitable for use in tropical climates, but this difficulty could be overcome by frequent replacement.

The consideration of plastics for the sight for the FN. 54 turret had been hampered by lack of reliable data and the behaviour of these materials under operational conditions in the air.[1] The use of plastics had been investigated by the Royal Aircraft Establishment and although the sights tested had been inferior to the glass ones, they were sufficiently good to use. The need for alternative sources of supply of components for the sight was emphasised when one of the firms undertaking the manufacture of lens blanks suffered damage by enemy action, although production of these particular glasses was unaffected.

A manufacturer of plastic lenses made up samples for test at the R.A.E. and National Physical Laboratory (N.P.L.). The crudity of the lenses and bulk of the sight rendered optical tests difficult, and a service trial was considered the most reliable method of checking the reaction of plastics, under operational conditions, to age, humidity and extremes of temperature and pressure. There was also doubt whether consistency of moulded lenses could be achieved in production and only a fairly large order could decide this point. Plastics were definitely inferior to the materials then being used and offered no functional advantages other than weight saving, but it was considered worthwhile to investigate the problem.

A plastic sight known as the Type 'A', Mark III, was tested at the R.A.E. in October 1941, mounted in a Blenheim aircraft.[2] The sight was flown through several layers of cloud and subjected to a temperature of minus 24 degrees Centigrade, and left all night on the aircraft after flight. No internal misting took place at any time during or after flights, although external misting, on descending through cloud had to be wiped off the outer surface of the upper and lower lenses. No breaking down of cement or other effect occurred which obscured vision. In view of the comparatively high temperature during the flight and since the conditions obtaining during and after the flight were such as to ensure the presence of internal moisture if any leaks had been present, the sight was given a fairly severe refrigerator test. No deposition of moisture could be detected on any internal surfaces after the sight had been subjected to a temperature of minus 40 degrees Centigrade. The standard metal and glass sight already fitted in the aircraft underwent the same flying tests and behaved in exactly the same way.

Although it appeared that the plastic sight was free from leaks and was adequately desiccated, it was possible in the return to normal room temperature

[1] M.A.P. File R.A. 1857. [2] A.M. File C.S. 10688.

after refrigeration, that, as the brass casing of the Mark II sight acquired heat more quickly than the glass, the deposition of moisture would generally take place on the glass where it was easily visible. With the plastic sight, however, all the materials were roughly of similar nature as regards conductivity and specific heat, and deposition of moisture might have occurred on the inside of the tube instead of on the lenses and so escaped notice. This was not considered likely, but a protracted service trial would be the best test.

The sight was heated to temperatures of 40 degrees, 50 degrees and 60 degrees Centigrade at each of which temperature it was kept for some hours. There appeared to be little change in optical characteristics after the first two of these tests, but after 60 degrees a certain amount of parallax was noticed. A second sight was heated to 50 degrees Centigrade and showed no parallax, but the definition was not quite so good as in its original state. It was considered that the sight would be capable of use up to a temperature of 50 degrees Centigrade and it was suggested that it should be accepted on ordinary optical tests.[1] The chief defects of the sights were undoubtedly due to the vagaries of the moulding, and it was known that better results could be obtained since an earlier sight had shown much better correction of the optical defects, but there would be difficulty in reproducing similar sights in production, and the sights produced had to be accepted.

Service trials of the sight were arranged in January 1942, to be carried out at R.A.F. Station, Manby, but it was not until October 1942 that the trials were completed. The sight was left out in the open for four days and nights and examined each day. There was no sign of condensation on the optical surfaces outside the aircraft, but the morning examinations showed slight condensation on the open surfaces inside the aircraft. The sight was cleaned by service personnel during the period of the trial and no scratches developed ; there was no sign of damage from ordinary handling, and it proved satisfactory on all tests.

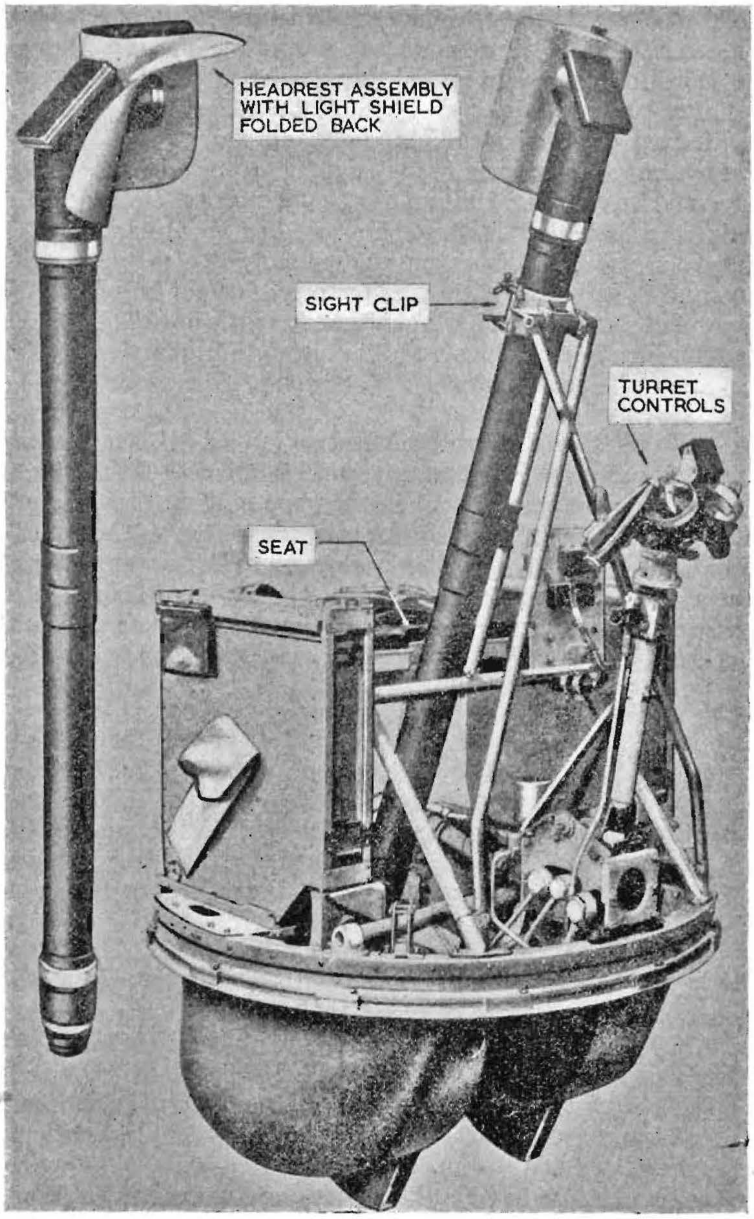
Towards the end of 1942 the only aircraft requiring the backward firing mounting of the FN. 54, FN. 60 and FN. 61 type turret was the Blenheim V. This aircraft was at that time used almost exclusively in the Middle East and the upper temperature limitation ruled out its use in this theatre. The sights had been manufactured as a standby in case supplies of the glass sights should be difficult and the bulk of the production order was held in reserve against a possible demand by home based aircraft.[2]

Type 'B' periscope sight

The restricted field of view of the Type 'A' sight had proved a great drawback in its use. In November 1940 a requisition was placed with Nash & Thompson for the design of powered under-mounting to replace the FN. 54A and FN. 60A turrets. The Royal Aircraft Establishment (R.A.E.) designed a sight which was discussed at a meeting in December 1940 ; manufacturing difficulties were foreseen in the design and it was decided that the sight should be modified to easier production, and to have a field of view approximately 60 degrees. The new design of turret, the FN. 64, was to be designed to take this sight.

[1] M.A.P. File R.A. 1857. [2] A.M. File C.S. 10688.

Basically the sight consisted of a unit magnification telescope with an inclined mirror interposed between the eye-piece lens and the telescope tube. The sight was rigidly held in a casting in the turret framework in such a position that it was above and in line with a prism which was held by the turret mechanism. A graticule was positioned in the telescope tube so that an image of a ring and bead appeared superimposed on the target when viewed through the sight.



PERISCOPIC GUNSIGHT, TYPE 'B', MARK II, AND THE FN. 64A UNDER DEFENCE TURRET WITH THE SIGHT INSTALLED

The prism was moved through actuating levers coupled to the guns in such a way that the line of sight was parallel to the axis of the gun barrels. In this way the sight tube did not move with the elevation or depression of the guns and thus differed from the Type 'A' periscope gun sight. This feature enabled the gunner to maintain a stable position on the turret seat through all movements of the guns. A shutter was provided to protect the prism when not in use.

Trials were carried out early in 1941 at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) on the prototype FN. 64 turret installed in a Stirling aircraft.[1] Beam and astern attacks were made simultaneously by Spitfire and Hurricane aircraft in daylight. Under moderate conditions of visibility there was not great difficulty in picking up the target at a range of over 600 yards, but in diving or other attacks where the fighter commenced the attack outside the field of view of the turret, it was not easy to detect the target quickly. Continual searching of the field of view for long periods, without external assistance, was very tiring. The sight permitted vision ahead of the beam, but the image became blurred towards the end of the field of view. This blurring occurred just outside the deflection ring and became progressively worse towards the edge of the field of view.

Continuous vibration of the sight occurred in the air and sighting was impossible when the guns were fired. It was considered that the removal of the arch which supported the top end of the sight would reduce this, the sight being stayed to some strong point in the turret framework. The whole of the sight and prism-drive mechanism was exceedingly fragile and would have to be completely re-designed. The drive should be completely enclosed to prevent damage and all backlash should be eliminated. It was also suggested that the prism and its drive should be integral with the turret and that the top part of the sight only should be made detachable. Thus when the sight was removed for any purpose, harmonisation would not be upset and there would be little possibility of damaging the prism. During the trial oil spots appeared on the prism and since the gunner could be misled by these, it would be necessary to make the prism accessible to permit cleaning in the air. This early sight was known as the Type 'B,' Mark I, but was never introduced into the Service.

Between 23 and 25 June trials were carried out with a modified sight known as the Mark II. The modifications suggested after the earlier trials had been incorporated. Sight vibration had been eliminated to such an extent that it was barely noticeable except when the guns were firing. Then however, it was severe, and would prevent accurate sighting if long bursts were fired. The vibration was of sufficiently low frequency for the target to remain visible. Oil was deposited on the two exposed surfaces of the prism and the outside lens at the bottom of the sight, and the makers suggested a spray of suitable solvent should be directed on to the surfaces.[1]

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[1] M.A.P. File R.A. 1694.

The Operational Requirements (O.R.) branch of the Air Ministry were concerned lest sighting by night proved impracticable and asked for an improvement in sight performance, if necessary at the expense of other features. It was proposed to tackle the problem in two ways :—

(a) By 'blooming' the present optical system.[1]

(b) By re-design to give larger exit lens which would double the magnification at a sacrifice of half the field of view.

It was considered that 'blooming' would only effect a partial answer, and concluded that a magnifying system would provide the more satisfactory answer. It was decided that magnification of two should be tried since higher powers would restrict the field of view unduly and render aiming difficult. The sight was to be interchangeable with the existing unit magnification sight as regards eye position, tube length, and angular rotation of prism.

Sight for use at night

A sight with double magnification and 30 degrees field was tested at the Air Fighting Development Unit (A.F.D.U.) in June 1942. On the first daytime flight the visibility was poor due to haze, and the sight was found to be of little value. The impression obtained was that the sight intensified the haze instead of improving the view. The slight haze encountered on the second daytime flight reduced the value of the sight. Tests at night, however, showed an improvement over the unit magnification sight.[2]

Meanwhile a prototype sight with bloomed lenses had been tested at the National Physical Laboratory (N.P.L.) with very satisfactory results. The increase in light transmitted was good, to be as high as 40 per cent., whilst the veiling glare had been reduced by 35 per cent.[3]

Further tests were carried out at A.F.D.U. in March 1943 to compare bloomed and unbloomed lenses in conjunction with the unit and two times magnification. The bloomed sights were better than the unbloomed for day or night use owing to the increased transmission of light. The 'bloomed' sight with the unit magnification was better than the bloomed sight with magnification of two owing to the reduced field of view of the latter. It was found that the turret was of little value for defensive fire at night as evasive action prevented the turret from being used effectively. These trials were not considered very satisfactory by the unit concerned as it was extremely difficult to compare two sights when it was impossible to mount them side by side. Changing from one sight to the other took about one minute and resulted in loss of night vision and some changes in position of the target in relation to the background.

As a result of these trials it was decided that the two times sight was unsuitable for night use owing to the restricted field, and also that deflection shooting with a magnifying sight required a special technique and hence special training. Blooming made a considerable improvement in ability to

[1] The glass/air surfaces were coated with thin film of oxides to reduce reflection losses.

[2] M.A.P. File S.B. 38811.

[3] M.A.P. File R.A. 1694 Part 1.

see aircraft at night, and there was no doubt that targets could be picked up at fairly long ranges on any but the darkest nights. As the requirement covered operations involving both day and night flying, the sight must be suitable for both purposes; it was not practicable to carry two sights and change them in the air. Consequently the sight with unit magnification and bloomed lenses would, it was considered, give best results at night and action was taken to have sights bloomed in production, the letter 'B' being added to the name plate to distinguish those with 'bloomed' lenses.

PART III

TURRETS

CHAPTER 12

AIRCRAFT TURRETS, 1931–1939

Inception of aircraft turrets

During the First World War, the role of military aircraft in general changed from one of pure reconnaissance to that of independent fighting units. At the end of the war aircraft were being categorised according to their respective roles, *e.g.*, bombers, fighters and reconnaissance aircraft. Armament had been developed to meet the needs of these different types and hence air gunners were included in aircraft crews to carry out offensive or defensive gunnery. They were accommodated in open cockpits and normally had one or two guns, mounted upon a scarff ring in such a way as to permit of a wide cone of fire to the rear.

Between the years 1919 and 1931 the design of gun mountings for open cockpits was improved but it became obvious that, as aircraft speeds had greatly increased, the gunner would have to be protected from the slipstream and given some form of assistance in manœuvring the gun against the increased air pressure. Accordingly the Air Ministry, in conjunction with aircraft contractors, started work on four separate ideas, namely :—

(*a*) To enclose fully the pilot and air gunner.

(*b*) To provide a rotating turret to house the air gunner.

(*c*) To provide the air gunner with special wind screens.

(*d*) To house the air gunner in the aircraft fuselage.[1]

Work on these schemes progressed steadily throughout 1932 and by October of that year, one contractor had designed and submitted a gun mounting which was completely 'servo' operated.[2]

This was followed in 1933 with three other schemes for complete servo operation.

Special Development Committee

As a result of this early work on the 'gunner problem' the Air Ministry decided, in April 1933, to form a special committee to study the whole question of gun mountings and installations. All aircraft contractors were informed that they should pay special attention to the problem of improving conditions for the air gunners. The Service requirements were made known and they were requested to submit their ideas and specimen installations for trial by the Air Ministry. Development progressed rapidly and in October 1933, the Air Ministry were able to place a contract for a servo operated gun mounting suitable for fitting to an operational aircraft.

[1] A.M. File S. 30460.

[2] *See* Chambers Technical Dictionary, 1943. A servo motor is a device for magnifying a relatively small effort, usually by hydraulic means.

Early development

During the years 1934 and 1935, further progress was made and certain refinements began to appear such as a stream-lined cupola to protect the air gunner, instead of screens, and a mechanically operated gunsight. In addition other servo operated systems were inspected and reported on and several were fitted to operational aircraft for service trials. Co-operation with contractors was fully established and all were furnished with the details of a mechanical gunsight drive to be incorporated in future designs. In addition demonstrations of current equipment were given to firms' representatives in order to spread current ideas and so assist development generally.

First attempt to standardise turret designs

Contractors continued the steady development of individual designs during 1936 and these included rear turrets for bombers and flying boats, under turrets for bombers and a special small reflector gunsight for use in turrets generally. At this stage, however, the Air Ministry decided to assist contractors still further by introducing turrets made to standard patterns so as to provide fully developed designs for incorporation in new types of aircraft. Accordingly turrets, made to the following standard patterns, were ordered :—

(*a*) Turrets with twin guns aft of the gunner.

(*b*) Turrets for the tails of heavy bombers.

(*c*) Turrets for underneath heavy bombers.

(*d*) Turrets for the tails of flying boats.

All these types were to be hydraulically operated. In addition, a development order was placed for an electro-hydraulic turret, carrying two 20-mm. guns, for use in two-seater fighters. This requirement shows that all concerned were beginning to appreciate the possibilities of power operated gun turrets. Not only were multi-gun turret designs now quite normal, but attention was being given to mounting much heavier weapons than the ·303 inch guns normally carried.

Progress during 1936 and 1937

The end of 1936 and the year 1937 were particularly outstanding for several reasons. It was during this period that some of the contractors, who later took the lead in turret production, began to emerge as the leading authorities on design. The firm of Nash and Thompson, Ltd., later known as Frazer Nash, in addition to continuing the development of the standard pattern turrets, gave advice and assistance to several other contractors. Two others were Boulton Paul, Ltd., and the Bristol Aeroplane Company, Ltd. Between them these firms were engaged in the development and production of turrets for all the operational aircraft in use or under development.

Probably the most difficult problem which arose was that of providing adequate ventilation in fully enclosed, multi-gun turrets, to prevent the gunner being gassed by the fumes produced in action. This matter, however, was successfully dealt with and by the end of 1937 a complete squadron of operational aircraft had been equipped with turrets and preliminary reports on their performance in service, were very encouraging. Finally, further progress was made in the design of pneumatic, hydraulic and electric gun firing mechanisms for use in turrets.[1]

[1] A.M. File S. 30460.

The efforts of one contractor during this period, are worthy of special note because, although his ideas appear to have had no influence on subsequent designs, they were quite revolutionary and deserved every encouragement. In the latter half of 1937, A. V. Roe, Ltd., in conjunction with E. H. Engineering, Ltd., submitted a scheme for a high pressure hydraulic system. Firms generally had accepted systems working with approximately 400 pounds per square inch hydraulic pressure, but these two firms intended to use a pressure of 4,000 pounds per square inch. The advantages of this were claimed to be as follows :—

(*a*) A large reduction in the size of pipe lines and operating units with a relative reduction in total weight and a marked saving in space.

(*b*) High pressures produced a much smoother and more positive action.

(*c*) Adequate pressure was available to the more remote parts of an installation.

(*d*) Such a system could also supply other aircraft services such as flaps and undercarriage, so simplifying and improving general design. In addition the projected turret could carry 20-mm. guns with an automatic servo ammunition feed as opposed to the awkward and unsatisfactory magazine feed being used at that time.

The firms were given all possible assistance but after two years' work, failed to produce the finished article and the whole idea was abandoned.[1]

Turrets to carry heavy calibre weapons, automatic sights and protective armour

At the beginning of 1938, turret production for all operational aircraft was well in hand. Unfortunately the development of fighter aircraft in Europe had reached a stage where guns of 20-mm. calibre were contemplated.[2] This called for immediate action to counter the threat and although the Air Ministry had already asked contractors to design turrets carrying 20-mm. guns, nothing had been produced and all the turrets in production mounted guns of only ·303-inch calibre. The leading contractors were accordingly requested to give immediate attention to this problem and by the end of 1938, three contractors were working on the following :—

(*a*) Boulton Paul, Ltd., were designing a fighter turret to carry four 20-mm. guns.

(*b*) Frazer Nash, Ltd., were designing a bomber turret to carry two '1½-pounder' guns (approximately 40-mm.).

(*c*) Vickers-Armstrong, Ltd., were designing a turret to carry two '2-pounder' guns (approximately 70-mm.).

Air Ministry took the view that very heavy gun turrets should be developed with a limiting diameter of approximately 10 feet. In addition they considered that an automatic 'predictor' sight was necessary to improve gun laying accuracy. This was intended to make automatic allowances for own aircraft speed, enemy speed and direction, etc., which had previously been left to the estimating capabilities of the gunner. Development contracts were therefore placed with the idea of producing heavy gun turrets, complete with predictor sights, as the answer to the new fighter threat. The magnitude of the predictor sight problem, however, was fully appreciated and no immediate solution was expected. Nothing was, in fact, achieved for several years.

[1] A.M. File S. 51588. [2] A.M. File S. 44412.

Concurrent with these major steps in development the Air Ministry also initiated action on the question of providing protective armour for aircraft and turrets, the protection of fighter aircraft being given precedence. Armour plate, varying in thickness between four and nine millimetres, was considered necessary and turret manufacturers were requested to study this problem without further delay.[1]

Design and production difficulties

Whilst the new problems of producing heavier turrets, better sights and protective armour were receiving the urgent attention of the contractors, discussion was taking place, at the Air Ministry, on development policy. The Air Staff considered that, as standard aircraft turrets were now available, the time had arrived to concentrate on the fitting of heavier guns and also to ensure that turret development in future, was kept well ahead of aircraft design in order to obviate the former serious difficulties experienced when trying to fit standard turrets to operational aircraft at too late a stage. Unfortunately, it was necessary at that time to use aircraft which were being developed or in production, as ' test beds ' for the new turret installations and this naturally led to a measure of disorganisation in the normal aircraft production programme. Strong objections were therefore raised by the Air Member for Design and Production who stated that whilst he fully agreed with the idea of developing 20-mm. turrets as quickly as possible, he deplored the necessity for using current development aircraft as, not only did this interfere with the rate of production, but he felt that it would also interfere with the original aircraft designs. He suggested, therefore, that the Chief of the Air Staff should take the necessary action to divorce completely turret development from aircraft design and production. After due consideration, in December 1938, the Chief of the Air Staff decided that the threat from heavily armed fighters could not be ignored and that every endeavour must be made to ensure that our own aircraft were adequately armed. Hence every effort must be made to fit 20-mm. guns to current types of aircraft even at the expense of major modifications to existing designs.

Aircraft and turret designers started work immediately to carry out the necessary modifications. Unfortunately, it quickly became apparent that the additional weight involved could not be dealt with in current designs and that the only position into which 20-mm. turrets could possibly be fitted was underneath bomber aircraft, close to the centre of gravity. Even the fitting of heavy turrets to the upper side of the fuselage, amidships, was found to require further investigation.[2]

The position at the beginning of the Second World War

As a result of the efforts and preparations made in the years 1931 to 1939 many of our operational aircraft were either fitted, or being fitted, with reasonably efficient power operated turrets before the start of the Second World War. These turrets, unfortunately, carried only small calibre machine guns and somewhat primitive gunsights but work was well advanced on greatly improved types of equipment.

The remaining chapters in this part deal in detail with the full development of the standard types of turrets used by the Royal Air Force, from their inception to the end of the Second World War.

[1] A.M. File S. 30460. [2] A.M. File S. 44412.

CHAPTER 13

AIRCRAFT TURRETS, 1939–1945

Although the power operated turret had reached a reasonable standard of efficiency by the end of 1939, the ideas and principles governing design were based largely on conjecture rather than specific knowledge. Operational use revealed fundamental weaknesses and, although greatly improved equipment was approaching the production stage in 1945, no major alterations were made to the turrets used during the war. Throughout the whole period attempts were made to adapt the turrets in production in 1939, to the changing demands of air operations, whilst revolutionary equipment was being developed. Such equipment, in the form of remotely controlled ' Barbettes ',[1] was almost ready for production when hostilities ceased. The equipment will be dealt with in a later chapter.

Vision

During the early part of the war, bomber aircraft flew at a fairly low level and, although no trouble was expected with existing equipment, night operations revealed the first weakness in design, *i.e.* failure to provide an unobstructed view for the gunner. The use of ' perspex ' for turret cupola panels, made night gunnery difficult because the panels were easily scratched or rendered useless by moisture, frost or the reflection from internal turret lights, searchlight glare etc. In October 1940, therefore, Bomber Command suggested that a part of the turret cupola should be cut away in order to provide a ' direct vision ' (D.V.) panel for use at night. They fully appreciated the fact that this would probably introduce a heating problem but considered that comfort would have to be sacrificed to efficiency. Accordingly manufacturers and the Royal Aircraft Establishment, Farnborough (R.A.E.) started work on suitable modifications and, by September 1941, had introduced a modification in the form of a sliding panel. This could be adjusted as required and hence the gunner could, to a certain extent, control his turret heat besides improving his vision. The Air Ministry accepted this as a temporary expedient and requested the R.A.E. to pursue the matter further.

In October 1941 the Director of Operational Requirements suggested that black-out paint should be used on the cupola panels, to reduce the glare from searchlights. The idea was accepted and forwarded for trial and shortly afterwards, in December, the Royal Air Force consultant in opthalmology rendered a report on the use of infra-red interior lighting as a means of cutting out dazzle and reflection. He reported a measure of success but had not reached any final conclusions. In January 1942, Bomber Command suggested that all bright metal parts should be painted black so the Air Ministry asked them to comment on the new standard finish recently introduced by Boulton Paul Ltd, *i.e.* black matt cellulose applied after sand-blasting. The Command commented favourably and the idea was adopted for all future equipment.

[1] ' Barbette ' —The name given to an uninhabited turret remotely controlled by a gunner, seated in a separate sighting station.

After further consideration, the Air Ministry decided that, as operational heights were increasing due to a steadily improving enemy night defence system, the question of improving turret vision and, at the same time preserving turret heating, would have to be considered on a high priority. Accordingly the Ministry of Aircraft Production and R.A.E. were requested to make every effort to find a more permanent and satisfactory solution than the D.V. panel. This action was followed in April 1942 by a protest from Bomber Command and the Air Staff, pointing out that, although the vision/heating problem had been first presented in October 1940, nothing of a really satisfactory nature was forthcoming. In the meantime, enemy night opposition was becoming really serious, operational heights were rapidly increasing and the D.V. panel was proving less satisfactory, particularly in the case of enemy fighters attacking from below the aircraft. Bomber Command were informed that a maximum effort was being made by all concerned but that, meanwhile, local modifications would have to suffice as no new equipment could be expected for some time.

In June 1942 a report was received on the use of 'black-out' paint as an anti-dazzle measure, suggested by the Director of Operational Requirements in October 1941. This stated that no advantage was to be gained unless a substantial proportion of the turret panelling was treated and, as this was unacceptable, the matter should be dropped. Shortly afterwards, however, two alternative anti-dazzle suggestions were made, one by Doctor E. Goldie of the R.A.E. and the other by the Royal Air Force Medical Branch. The first idea was the provision of an anti-dazzle shield around the base of the turret and the second proposed the issue of special anti-dazzle goggles. Both schemes were accepted for trial and at the end of 1942 a conference was held at the R.A.E. to discuss all the anti-dazzle measures proposed to date. After consolidating available information, the following recommendations were made :—

(*a*) The possibility of using glass for turret cupola panels to be investigated.

(*b*) Perspex panels to be replaced at regular intervals so as to minimise reflection due to scratches.

(*c*) A protective paper covering to be used on perspex during production processes and to remain in position as long as possible.

(*d*) Cupola covers, for ground use, to be held clear of the perspex panels by suitable packing pieces as even soft cloth will scratch perspex.

(*e*) A special wax polish to be used for cleaning purposes.

(*f*) A surface hardening process to be used on all perspex intended for turrets.

(*g*) The testing of the proposed anti-dazzle goggles and screens to proceed as quickly as possible.

By January 1943 the anti-dazzle screen, suggested by Doctor Goldie and known as the 'Pask' screen, had been tested and rejected. It was found impossible to exclude the glare from searchlights at long range and, as this was equally as bad as that from searchlights close in, the idea was abandoned.

Bomber Command again called for urgent action and stressed that their losses were being caused mainly by fighters attacking from below. They considered that major changes were required in turret design and pointed out that the introduction of more guns in turrets, more ammunition, protective armour and electrical feed assisting devices was making the gunners' vision worse instead of better. In April 1943 therefore, after careful consideration of the major problems involved in new designs, Air Ministry asked Bomber Command to state their minimum requirements under the following main headings :—

(*a*) Field of fire and fire power, *i.e.*, numbers and calibre of guns with limiting arcs of fire.

(*b*) Ammunition load per gun.

(*c*) Protective armour.

All these factors directly influenced general turret layout and hence, vision and comfort. At the same time Bomber Command were informed that work was progressing favourably on a radar assisted, blind firing device (known as A.G.L.T., *i.e.* assisted gun laying turrets) combined with a remote turret control system which should solve all the current turret problems. The Commander-in-Chief replied stating his requirements, but making it quite clear that he was in favour of a simple D.V. panel rather than a radar sighting device because of the apparent ease with which radar and radio countermeasures could be produced.

After further correspondence on the subject the Commander-in-Chief, Bomber Command, informed the Air Ministry in June 1943, that he was dissatisfied with the current development programme as it was not allied, closely enough to operational requirements. He considered that the problem of heavy bomber armament had become so complicated that a conference should be held at the Air Ministry with a view to evolving a more realistic development policy ; particularly with regard to the question of improved vision. The Air Ministry agreed to this measure but it subsequently became apparent that the ideas developed in Bomber Command were far too sweeping and, in particular, called for unattainable changes in aircraft design. Furthermore, their propositions ignored the existence of such items as the new predictor gunsight (Gyro Gunsight or G.G.S.) radar assisted sighting (A.G.L.T.) and remote control, all of which were designed to solve the bomber armament problems. It was finally decided therefore, to adhere strictly to the development programme in hand which included the following :—

(*a*) Heavier weapons for bomber defence, *i.e.*, ·5-inch and 20-millimetre guns in turrets.

(*b*) More accurate gunsights, *i.e.*, the gyro gunsight, capable of making accurate automatic allowances.

(*c*) Radar assisted sighting to improve night search and make blind firing possible. (A.G.L.T.)

(*d*) Turrets (or Barbettes) remotely controlled by the gunner from an independent sighting station giving him maximum visibility and comfort.

(*e*) Improved aircraft performance resulting from the better streamlining possible with a remote control system.

This programme was far beyond the scope of anything suggested by Bomber Command and was considered to be the only complete solution to the bomber armament problem. The first remote control system, embodying all the points mentioned above, was not air tested until 1945 and was too late to be put into production before hostilities ceased. In the meantime, operational aircraft finished the war with armament which differed very little from that in use in 1939.[1]

Heating

A few of the early turrets were fitted with heating devices which by-passed heat from the engines. Some manufacturers were experimenting with different forms of heating devices, on a private venture basis, otherwise nothing positive had been done to provide heat in aircraft turrets. The Ministry of Aircraft Production encouraged firms as far as possible, because they considered that heaters were a probable future requirement in all aircraft. In the winter of 1941, however, the lack of heat, particularly in rear turrets, began to impair the efficiency of the aircrews. D.V. panels had, of course, to remain in use but Bomber Command considered that much could be done to reduce draughts in the turrets and so improve comfort. Accordingly between December 1941 and March 1942 they applied for permission to incorporate two local modifications, both of which were simple devices for sealing openings in the turret structures. These were approved and passed to the manufacturers for incorporation in future products. In addition, the Director of Technical Development immediately called a conference, at which it was agreed that the heating problem should be co-ordinated with the work already being done to improve vision, and that both should be given the highest priority by the R.A.E.

Little progress was made during the following year, mainly because effort was being concentrated on the vision problem rather than heating. The R.A.E. did, however, make a series of air tests, terminating in August 1942, to measure the draughts caused by the D.V. panel and normal structural openings and as a result recommended the fitting of aircraft bulkheads. At the same time a conference was held at the Air Ministry to discuss the 'protection of aircraft crews' with representatives of Bomber Command and the Ministry of Aircraft Production. This resulted in a recommendation for the development of electrically heated clothing for rear gunners only. A second conference in December, organised by the Director of Technical Development, decided that electrical heating should be provided for both the gunners and the guns and that independent turret heating units should be developed.

In January 1943, Bomber Command reported another problem connected with increasing operational heights, and already foreseen by the Air Ministry, *i.e.*, guns freezing up completely. They asked for permission to use 'Intava' brand anti-freezing oil for gun maintenance, to replace the standard fifty per cent. mixture of paraffin and oil (Specification D.T.D./44C) specified by regulations. The Air Ministry decided that a change of lubricating oil was unlikely to prove satisfactory, and that the only solution was adequate gun and turret heating so the Ministry of Aircraft Production was requested to investigate this matter on the highest priority. As a result of experiments already in hand, the R.A.E. were able to report, in February 1943, that an electric gun heater was available which would raise the temperature fifteen to twenty degrees centigrade. In addition, a separate turret heater was nearing

[1] A.M. File S. 7011.

completion but the problem of ensuring a satisfactory output, above 25,000 feet, was causing some difficulty. The following month they reported a further improvement, achieved by fitting cellophane paper seals over gun ejection openings, etc., thus raising the temperature as much as thirty degrees centigrade.

Although every effort was being made to produce satisfactory heating devices, the situation gradually deteriorated and the Secretary of State for Air asked the Director of Operational Requirements for a statement on the subject. His reply stressed the difficulties involved, which included the following :—

(*a*) The presence of a D.V. panel made satisfactory heating almost impossible.

(*b*) Over-oiling of guns, due to poor maintenance, rendered them prone to freezing.

(*c*) Greatly increased operational heights. He pointed out that on the average winter flight from England to Berlin at 20,000 feet, the mean temperature was minus 25° C. Temperatures as low as minus 50° C. were on record and the guns were only cleared down to minus 38° C.

(*d*) Moisture deposited from clouds, etc., formed hard ice which jammed gun mechanisms.

This led to a Ministry of Aircraft Production conference, in June 1943, specifically charged with the onus of providing adequate turret heating, particularly in rear turrets, before the winter of 1943–44. The following conclusions and decisions were reached :—

(*a*) On the advice of the R.A.E. simple draught reducing modifications were to be devised. These should reduce draughts to less than four cubic feet per second. Usually they were found to be approximately twenty cubic feet per second.

(*b*) Heating units must produce temperatures of not less than 0° C. at 25,000 feet. This would require approximately 10 H.P.[1] assuming a leakage rate of four cubic feet per second.

(*c*) The normal aircraft electric power supply was considered inadequate for general heating but satisfactory for heated clothing and individual gun heaters.

(*d*) Adequate heat for all nose and amidships turrets should be available from the aircraft engines using heating ducts.

(*e*) Separate unit heating would definitely be required for rear turrets. At the time there were four heaters being developed, *i.e.*, Ascot, Tecalemit, Stewart-Warner and Gallay. Of these it was decided to develop the Gallay ; a simple device using paraffin as a fuel.

On the 15 June 1943, Bomber Command reported that local tests had shown that guns were much less likely to freeze if American oil, AXS-777, was used instead of the normal anti-freezing oil issued by the Service ; the matter was referred to the R.A.E. for consideration. Shortly afterwards a query arose concerning the probable vulnerability of unit heaters, using highly inflammable

[1] Heating engineers use ' Horse Power ' as a means of expressing the capacity of a heater. (778 ft./lb. equals one British Thermal Unit).

fuels or by-passing engine coolant. In the first case however, as the Gallay heater used paraffin and the whole mechanism was enclosed in a sturdy metal box, it was considered to be quite safe. Should heaters be developed which by-passed the engine coolant, it was decided to fit an automatic cut-out to prevent loss of coolant, in case of damage, and so obviate the risk of engine seizure. The cut-out however was considered likely to cause some delay in the design department so the Director of Technical Development was asked for an assurance that immediate positive action would be taken to speed development. He replied that, whilst every effort was being made to meet heating requirements before the end of 1943, he felt personally that it was doubtful whether all demands could be met. However, to ensure that everything possible was being done, he instituted Ministry of Aircraft Production Progress Meetings to keep a careful check on the development programme.

The first progress meeting was held at the end of July 1943 and discussed the results of recent Bomber Command trials which suggested that freezing of the front gun barrel bearings was the main cause of trouble with the guns. As a result the following suggestions were passed to the Director of Armament Development for investigation :—

(*a*) Parts likely to freeze, to be sprayed with alcohol.
(*b*) An improved lubricant or de-icing paste to be sought.
(*c*) Covers to be made for gun barrels and muzzle openings.

In October 1943, the answers to these suggestions were contained in a report from the R.A.E. on recent 'cold' tests done on standard service equipment. Among other things, these tests showed that guns, after normal servicing, fired efficiently down to minus 40° C. and lower still with gun heaters fitted. Furthermore, ice on front barrel bearings had no effect on gun functioning. Finally Service oils (D.T.D. 44D. or D.T.D. 44D. plus 50 per cent. paraffin) showed to advantage when compared with the American oil (AXS-777) suggested by Bomber Command in June. The latter had been abandoned by the Americans after similar trials in Alaska ; the viscosity was too high for light machine guns.

December 1943 brought a protest from Bomber Command, strongly supported by the Air Staff at Air Ministry, at the general lack of progress. The only possible reply, however, was given by the Controller of Research and Development, *i.e.* everything possible was being done. Accordingly, the Chief of the Air Staff asked for immediate emergency measures to be taken, as the worst winter months were ahead. Nothing could be done, however, beyond the provision of heated suits for the gunners and the modifications incorporated to cut down draughts.

The next incident of importance was a progress meeting, held in June 1944, which summarised the work on turrets as follows :—

(*a*) Research showed that reliance should be placed on unit heaters, rather than on those which employed engine waste heat. Up to 100 h.p. would be required, per aircraft, to meet all demands fully.

(*b*) The types of heaters tested showed the following relative efficiencies :—

(i) Electrical ..	.. 25 per cent.
(ii) Engine ..	.. 30 per cent.
(iii) Unit heaters	.. 75 per cent.

(*c*) The Gallay heater was not yet available due to unforeseen difficulties; mainly the erratic burning, which occurred at high altitudes. No provision had been made for altitude compensation, the burner could be extinguished by lack of fuel, due to gravity effects during manoeuvres and it was very difficult to restart above 10,000 feet. However, it was hoped to overcome these troubles by September 1944.

(*d*) The Americans had produced an electric unit heater known as the Grey-Selas, which should be available by January 1945.

(*e*) The main difficulty with heating was still the necessity for a D.V. panel in the cupola. Unless this could be done away with, there seemed to be little hope of meeting Bomber Command's requirement for a turret temperature of plus 10° C. with an anambient air temperature of minus 50° C.

The climax came in August 1944 when the Gallay heater had to be rejected completely as no solution could be found to the erratic performance at high altitudes. In addition, the American Grey-Selas heater became available but as it required approximately 550 watts to operate, it was totally unsuitable for British aircraft. The result was that efforts were switched to the rapid development of the remote control system as the only reliable answer, and nothing further was attempted before the end of hostilities.[1]

Controls

Prior to 1941 manufacturers developed their turrets strictly according to their own ideas. One result of this was that the gunners' controls varied with the make of the turret, leading to training difficulties and a lowering of efficiency, *i.e.*, gunners were not easily interchangeable between different types of aircraft nor, indeed, between different types of turrets in the same aircraft. The Air Ministry decided in April 1941 therefore, that controls should be standardised.

The two types of controls mainly in use were the Frazer Nash, or 'handlebar' type and the Boulton-Paul, or 'joystick.' The former provided the gunner with a pair of short hand grips sloping downwards and outwards; rotation of the turret was achieved by rotating the grips in the horizontal plane as when steering a bicycle, and elevation or depression of the guns by rotating the grips around their own axes. The 'joystick' produced movement of the turret or guns by the manipulation of a short control column, similar to that of a light aircraft; movement backwards or forwards elevated or depressed the guns whilst movement left or right produced turret rotation.

As in all such cases the Air Ministry called for the opinions and recommendations of the users as well as those of the scientific establishments. In addition they asked for any other suggestions for improving comfort or crew efficiency such as adjustable seats, stowages for heated food in 'thermos' containers or cheek rests for gunsights. Initial returns showed the usual wide divergence of opinions. Some members of the Central Gunnery School, whose instructors all had operational experience, thought that the 'handlebar' control was more natural and was so arranged as to give the gunner more room in the turret.

[1] A.M. File S. 7011.

Others preferred the 'joystick' because they found it easier to handle when under the influence of gravity. On the scientific side, the Gunnery Research Unit considered that the 'joystick' was superior in that it provided vector control, *i.e.* combined movement in the vertical and horizontal planes, more naturally than the 'handlebar.' In addition it was possible to fit the 'joystick' with supports for the wrists and forearms so ensuring greater sensitivity.

In May 1941 the Central Gunnery School forwarded further observations and added the following list of points to be considered in designing the ideal control :—

(*a*) Control handles to be placed centrally in front of the gunner.

(*b*) The controls should turn horizontally to produce movement in azimuth and require fore and aft pressure for depression or elevation.

(*c*) A 'push button' should be provided for firing the guns.

(*d*) There should be speed control in the form of a push button, giving maximum output when fully depressed. High speed was not normally required for single targets but very essential when a sudden switch became necessary.

(*e*) The controls should provide a natural position for the hands, with support for the wrists and forearms to assist when under the influence of gravity.

(*f*) The controls should be non-metallic so as to assist in keeping the hands warm.

(*g*) There should be a positive neutral position to prevent the turret creeping with the controls at rest. Following this other units and formations forwarded further suggestions but, on the whole, the majority were definitely in favour of the 'handlebar' controls. They were, therefore, accepted by Air Ministry as the standard for all types of turrets and subsequent models incorporated them.

Comfort

Probably one of the most awkward problems arose early in 1942 and although a fairly quick solution was found, it serves to illustrate the careful attention to detail necessary when designing aircraft turrets. Reports began to arrive from units that many air gunners were dissatisfied, and applying for posting, because they were too big to fit comfortably into their turrets. The Director of Personnel, Air Ministry, referred the matter to the Director of Operational requirements and an investigation disclosed the following :—

(*a*) The smallest turrets were those made by the Bristol Aeroplane Co. Ltd., the largest those made by Boulton-Paul Ltd., with Frazer Nash turrets in between. American turrets, in the course of development and likely to be used later, were smaller than the Bristol products.

(*b*) Adjustable turret seats were being developed and in the meantime cushions, of varying thickness, would have to be used.

(*c*) A gunner of average size could comfortably use all turrets other than Bristol's ; personnel above average size could only use Boulton-Paul turrets.

Further enquiries by the Flying Personnel Research Committee showed that only small men, *i.e.*, under 5 feet 6 inches in height with a girth of not more than 54 inches in full flying kit, could comfortably use Bristol turrets.

The Director of Personnel solved the problem by arranging for gunners to be graded, physically, during training and posted to squadrons accordingly. This was the best that could be done but led to increased documentation and the limitation of inter-changeability of personnel.[1]

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[1] A.M. File S. 7011.

CHAPTER 14

FRAZER NASH TURRETS

Five sources of power were available for the operation of aircraft turrets, *i.e.*, pneumatic, hydraulic, electric, electro-hydraulic and electro-mechanical. Of these, the pneumatic method was abandoned at an early stage because the compressibility of air, and the varying slipstream loading on the guns, made positive control impossible.[1] All the others were employed successfully by different manufacturers, although electricity was definitely taking precedence by the end of the Second World War.

The firm of Frazer Nash Ltd., selected hydraulic power and although they were concerned, either directly or indirectly, with the development of other systems, all their production turrets used hydraulic power throughout. Furthermore, although they developed and produced turrets for all types of aircraft and all aircraft positions, the basic components remained the same and were simply modified or re-arranged as required. A large amount of experimental work on various types of turrets, using weapons up to 40-mm. calibre and different powering systems, was also undertaken by this firm but the following history is confined almost exclusively, to the hydraulic turrets actually developed, produced and used in operational aircraft.

Up to the outbreak of war, the Air Staff requirements as to the types of turrets to be developed, *e.g.*, nose and tail, etc., had necessarily to be based on a theoretical, rather than practical assessment and were modified later, as operational experience was gained.

In the early stages, Frazer Nash Ltd., identified their turrets by referring to the type of aircraft for which they were produced, and the position in the aircraft, *e.g.*, Wellington, tail. This system had to be altered as turret designs improved and they became standard equipment for different types of aircraft. All turrets were then given a serial number, prefixed by the initials 'FN'; starting from FN. 1 and running consecutively as they were developed, irrespective of the aircraft or position for which they were intended.[2]

The Frazer Nash hydraulic system[3]

In the Frazer Nash system power was derived from oil, circulated under pressure, by an engine driven pump.[4] The turret was rotated by a hydraulic motor and the guns were elevated, or depressed, by hydraulic ram(s). The gunner produced the necessary movements by manipulating his control handles, so operating valves, housed in a valve box which was situated in the turret. Each turret had an independent hydraulic system so that, in an aircraft fitted with several turrets, there were the appropriate number of engine driven pumps, etc. The complete system was divided into two parts, one being the external

[1] R.A.E. Report No. Arm. 203, dated April 1948.

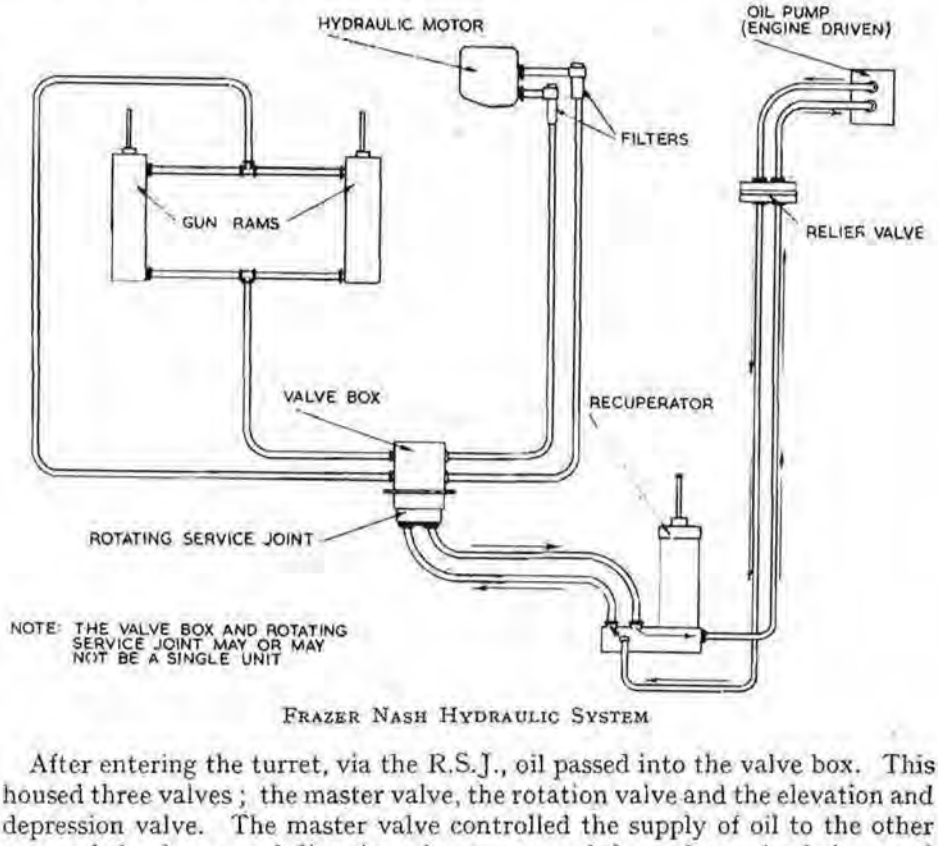
[2] A complete numerical record of Frazer Nash turrets will be found at Appendix 1. This includes experimental types and a few leading particulars.

[3] A.P. 1659A. Volume 1.

[4] For all FN. turrets, the pressure was approximately 300 lb. per square inch, with a flow of six to eight gallons per hour.

oil supply and return from the engine driven pump to the rotating service joint (R.S.J.) on the turret and the other, the internal supply and return within the turret structure; from the R.S.J. to the valve box, rotation motor and gun ram(s).

In the external part of the system, oil was passed from the engine driven pumps through a relief valve, set at approximately 300 lb. per square inch, which by-passed oil back to the return side of the system as necessary. The oil was then fed into a 'recuperator,' which acted as a reservoir for the oil under pressure and compensated for small losses of oil in the system or any changes in volume due to temperature variations. From the recuperator it passed to the inlet port of the R.S.J., and so into the turret system. On the return side it was passed from the R.S.J. through the recuperator and so back to the inlet port of the engine driven pump.



FRAZER NASH HYDRAULIC SYSTEM

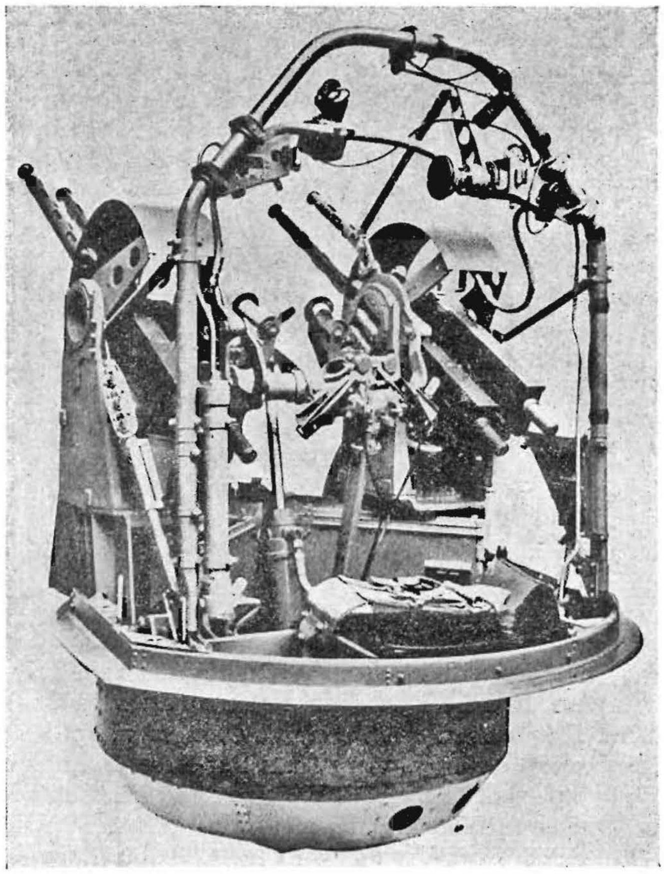
After entering the turret, via the R.S.J., oil passed into the valve box. This housed three valves; the master valve, the rotation valve and the elevation and depression valve. The master valve controlled the supply of oil to the other two and the degree and direction of movement of these, determined the speed and direction of movement of the rotation motor and gun ram(s). When the gunner gripped the control handles a small lever operated the master valve. Rotation of the control handle grips about their own axes produced vertical movement of the guns and rotation of both grips about the vertical axis, produced rotation in azimuth.

In early turrets the guns were fired by a hydraulic mechanism, using oil tapped from the turret system, but an electrical firing system was introduced later. This was more reliable and less complicated than the hydraulic device.

Tail Turrets

Early Development.—The Air Staff decided, in June 1936, that heavy aircraft were more likely to be attacked from astern, than any other direction, and arranged for the development of tail turrets, carrying four ·303 calibre machine guns where possible, as this was the heaviest defensive armament practicable at that time. The armament firms were invited to study the possibility of fitting heavier calibre weapons in the turrets, although the inherent problems were known to be extremely difficult and unlikely to be solved for some time. In particular, as stated already, conventional aircraft could not carry extra weight in the tail without altering the centre of gravity beyond permissible limits.[1] Between the date of this decision and the outbreak of hostilities in 1939 Frazer Nash Ltd., developed, and produced, four tail turrets for heavy aircraft namely the FN. 4, FN. 5, FN. 13 and FN. 15.[2]

FN. 4 Turret.—The FN. 4 turret carried four ·303 calibre Browning guns and was produced for heavy bombers and flying boats. The power system was

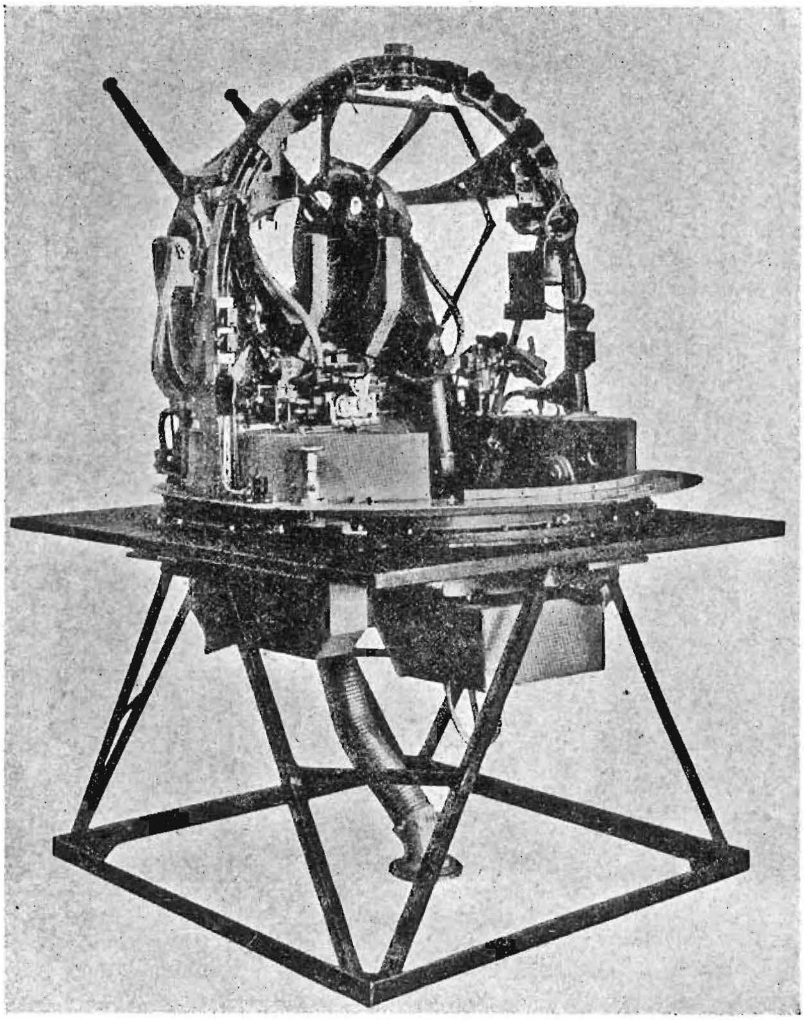


FN. 4 Tail Turret
(with Cupola removed)

[1] A.M. File S. 38527. [2] A.M. Files S. 40838 and S. 41296.

completely hydraulic, including the gun firing mechanism and employed the standard components already described. The general design and layout persisted throughout a full range of turrets produced subsequently.[1]

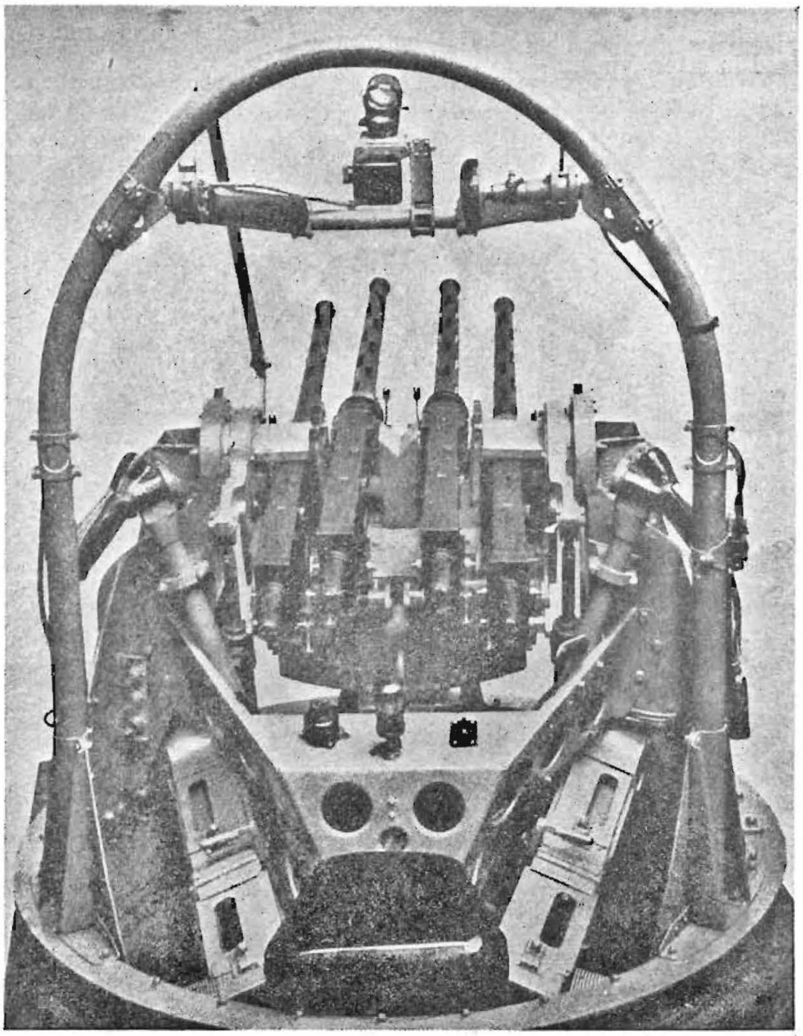
FN. 5 Turret.—This turret carried two ·303 calibre Browning guns and was fitted in the tail of one type of heavy bomber but was also used in the nose of several others. It was a conventional FN. turret in all respects and the design was used in later types.



FN. 5 TAIL TURRET
(WITH CUPOLA REMOVED)

[1] A.P. 1659A Vol. 1 Chapter 10.

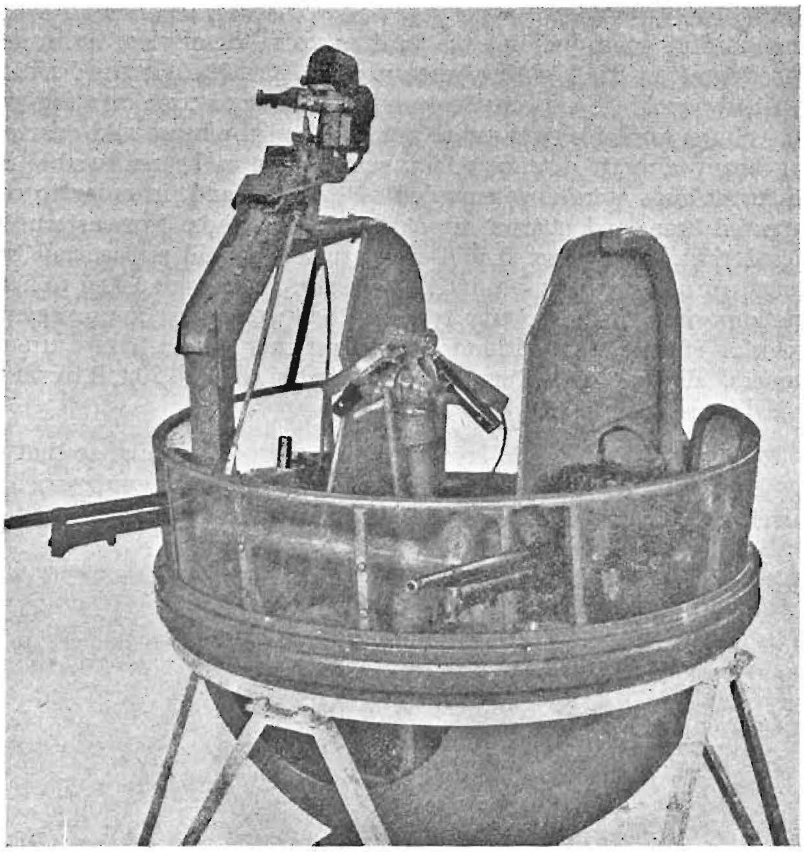
FN. 13 Turret.—Built for the tail of a flying boat, this turret differed from the FN. 4 in the general internal layout only. It carried four ·303 calibre Browning guns.[1]



FN. 13 TAIL TURRET
(WITH CUPOLA REMOVED)

FN. 15 Turret.—This turret carried two ·303 calibre Lewis guns and was produced for the nose and tail of a heavy bomber. It employed the conventional FN. hydraulic system but the guns were fired by a simple cable device and ammunition was fed in pans instead of belts.

[1] A.P. 1659A. Vol. 1.



FN. 15 Tail Turret
(with Cupola removed)

Early technical improvements

During the initial phase of turret development, certain basic technical defects, applicable to all types of turrets, had to be rectified. The first one concerned the use of magnesium alloy castings for valve boxes etc. This alloy was used in an attempt to reduce weight, as far as possible, but experiments showed that oil pressure and heat caused serious leaks due to the micro-porosity of the metal and in addition, it corroded very quickly when used on marine aircraft. The defect was overcome by using duralumin.

The second defect arose from the use of red fibre as an insulating medium for the turret electrical circuits, *i.e.*, lighting and inter-communication. Under Service conditions, the insulating properties of the red fibre proved unsatisfactory and it was replaced by ' Tufnol,' a proprietory laminated product.

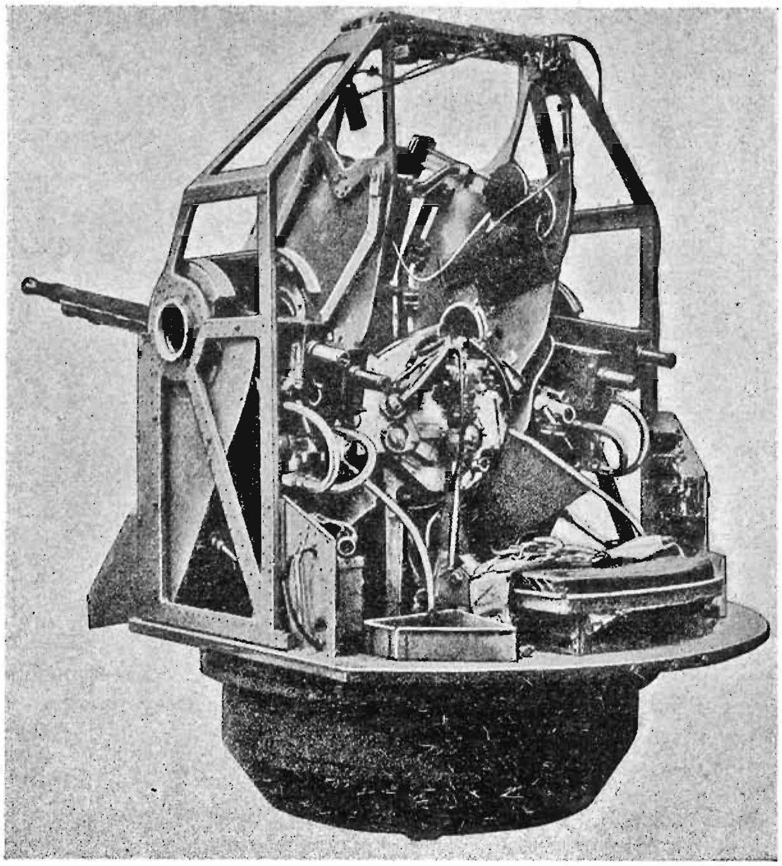
A third defect was due to the use of duralumin for seat springs, in a further endeavour to reduce weight. This proved to be unsatisfactory however, and had to be replaced by normal spring steel.[1]

[1] A.M. File 666518/37.

Operational requirements

War conditions soon disclosed the weaknesses in the original turret designs. At a meeting of the Air Fighting Committee in April 1940, it was decided that as the enemy could be expected to produce fighter aircraft carrying guns of 20-mm. calibre, and also to develop attacks from the beam and quarter, the existing heavy aircraft defence policy would have to be reviewed.[1] Heavy calibre turret guns were now regarded as essential and, in order to combat the expected beam and quarter attacks, as well as those from astern, it was considered that heavily armed mid-upper turrets should replace tail turrets. Until such turrets could be produced, however, firms were asked to make all possible improvements to existing types. The first positive improvement was the provision of more ammunition for tail turret guns and protective armour for the gunners. Both these features were included in the FN. 20 tail turret which was issued for service in 1940.

FN. 20 Turret.—The general layout of this turret was similar to that of the FN. 4. However, instead of 1,000 rounds of ammunition per gun, carried inside the turret, 2,500 rounds per gun were stowed externally and the belts were



FN. 20 TAIL TURRET
(WITH CUPOLA REMOVED)

[1] A.M. File S. 3486.

drawn into the turret through special ducts at the base, by means of a hydraulic motor. Protective armour plate was fitted to the front of the turret, immediately in front of the gunner, and moved up and down with the guns, so giving protection as the guns were elevated and ensuring a clear view when the guns were depressed. Apart from these refinements there was no other major alteration to the general design.[1]

By the middle of 1941, Bomber Command were presssing for the improvement of the gunner's field of vision. The only immediate solution was either, to remove complete panels of perspex from the turret cupolas, or to cut away part of a panel and fit a sliding trap.[2] Both these ideas were adopted and the urgent need for better vision led to the production of the FN. 120.

FN. 120 Turret.—This turret was a modified version of the FN. 20. Certain minor items of internal equipment were removed or repositioned and the cupola was modified to give the gunner a better field of vision. It was available for service in 1943,[3] and was often referred to as a 'filletted' FN. 20.

In addition to this urgent improvement of turrets in operational use the Air Staff called for long term development action, to produce pressurized turrets for future high altitude aircraft. Accordingly work was started in 1941 to pressurize a standard FN. 20, designed to withstand an internal pressure of plus two pounds per square inch. This project was altered later to the development of a new pressurized turret, suitable for any heavy aircraft and to be known as the FN. 73. Pressure of other development work however, led to a reduction in the priority of this task and by June 1942, it was virtually abandoned and never progressed beyond the prototype stage.[4]

The final phase of tail turret development

During the period 1942 to 1943, two major technical developments produced equally important improvements to aircraft turrets generally. The first was the introduction of the gyro gunsight and the second, the fitting of the radar sighting aid, which made long range sighting and blind firing possible. Immediately these became available, action was taken to put them into operational use. A contract was placed for the production of turrets FN. 121, FN. 122 and FN. 123, in addition to a 'super-filletted' version of the FN. 120, to be known as the FN. 220. These were all basically similar and so it was eventually decided to cancel all except the FN. 121.[5]

FN. 121 Turret.—This was really a modified FN. 120 and was equipped with an electrically operated servo ammunition feed, to replace the old hydraulic unit, a gyro gunsight and the radar attachment. The FN. 121 represented

[1] A.P. 1659A Vol. 1, Chapter 14. [2] A.M. File S. 7011.

[3] A.M. File S. 91573. [4] A.M. Files S. 7011 and H.S. 68226.

[5] A.M. Files S. 95371, S. 91573, H.S. 73170, S. 103537 and S. 99038. Also M.A.P. File S.B. 55720/2.

[6] A.P. 2799F. Vol. 1.

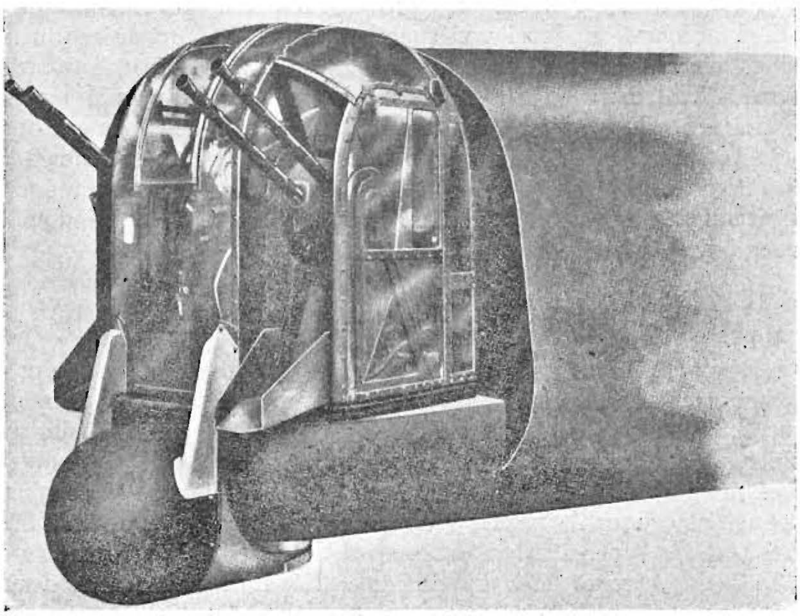
the best that could be done, at short notice, to bring tail turrets up to date but it was regarded as a compromise only. The intention was to replace it, as quickly as possible, with a fully modernised tail turret, re-designed to provide the best possible view, in addition to incorporating the new sighting devices. Furthermore, operational records showed that electrical turret systems were less vulnerable than hydraulic. A discussion was held at the Air Ministry in March 1942 and it was decided that, where possible, hydraulic pipe lines would have to be re-routed to clear the more vulnerable parts of aircraft, and duplicated in order to prevent turrets being put out of action completely, by chance hits on the pipe lines. It was agreed also that all future designs should aim at the full employment of electricity in aircraft turrets, for the following reasons :—

(*a*) An electric cable could be damaged by a bullet and still transmit power.

(*b*) Cables presented a much smaller target than pipe lines.

(*c*) The flexibility of cables simplified the problem of routeing to avoid vulnerable areas.

(*d*) Cables could be duplicated easily and repaired in flight.[1]



FN. 121 Tail Turret
(Showing the Radar Scanner)

As a result of all these considerations, a contract was placed early in 1943, for the development of the FN. 82 tail turret. In addition to incorporating the latest ideas, this turret was designed to carry ·5 calibre Browning guns instead of ·303. Unfortunately the idea of using an all electric system had to be abandoned at an early stage, in the interests of urgency.[2]

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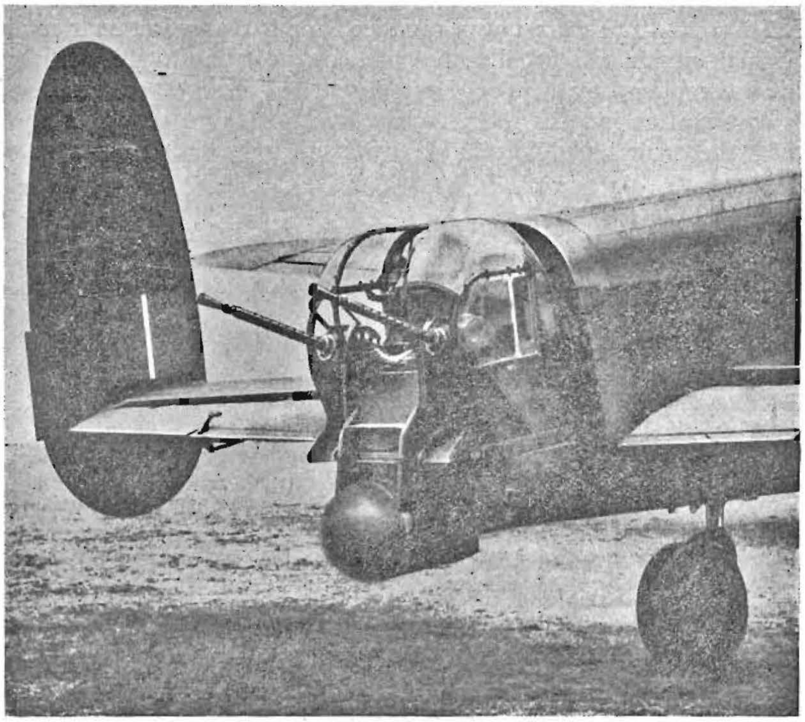
[1] A.M. File C.S. 13435. [2] A.M. File C. 38133/48.

FN. 82 Turret.—This turret was passed for service use in 1944 and although employing a conventional FN. hydraulic system, every endeavour had been made to provide an unobstructed field of vision. The equipment included two ·5 calibre Browning guns, gyro gunsight and radar attachment and the design was a great improvement on the older types of turrets.[1]



FN. 82 Tail Turret
(Showing the Radar Scanner)

Upper turrets

Turrets positioned on the upper side of an aircraft fuselage, usually mid-way between the nose and tail, were often referred to by different names, *e.g.*, centre, upper, mid-upper, midships or dorsal. They were produced originally as a result of the Air Ministry deliberations in 1936, already referred to.[2] Unlike other types of turrets they were used not only for the defence of heavy aircraft, but also as offensive armament for two-seater fighters. The provisional policy introducing them as defensive armament, became more positive in 1938, when ideas on heavy aircraft defence began to change. Research showed that it was almost impossible to fit heavy calibre guns in the tails of conventional heavy aircraft and that an attempt to do so would probably involve re-designing as much as 30 per cent., plus the time taken to develop a new turret. This was considered to be prohibitive and produced the idea of replacing both nose and

[1] A.P. 2799Q Vol. 1. [2] ' Tail Turrets—Early Development '.

tail turrets by heavily armed upper and under turrets.[1] Heavier calibre guns were not adapted to aircraft turrets until much later however, and in the interim upper turrets were produced using the lighter calibre guns available. These provided a measure of reinforcement for both nose and tail turrets, as well as defence against beam attacks.

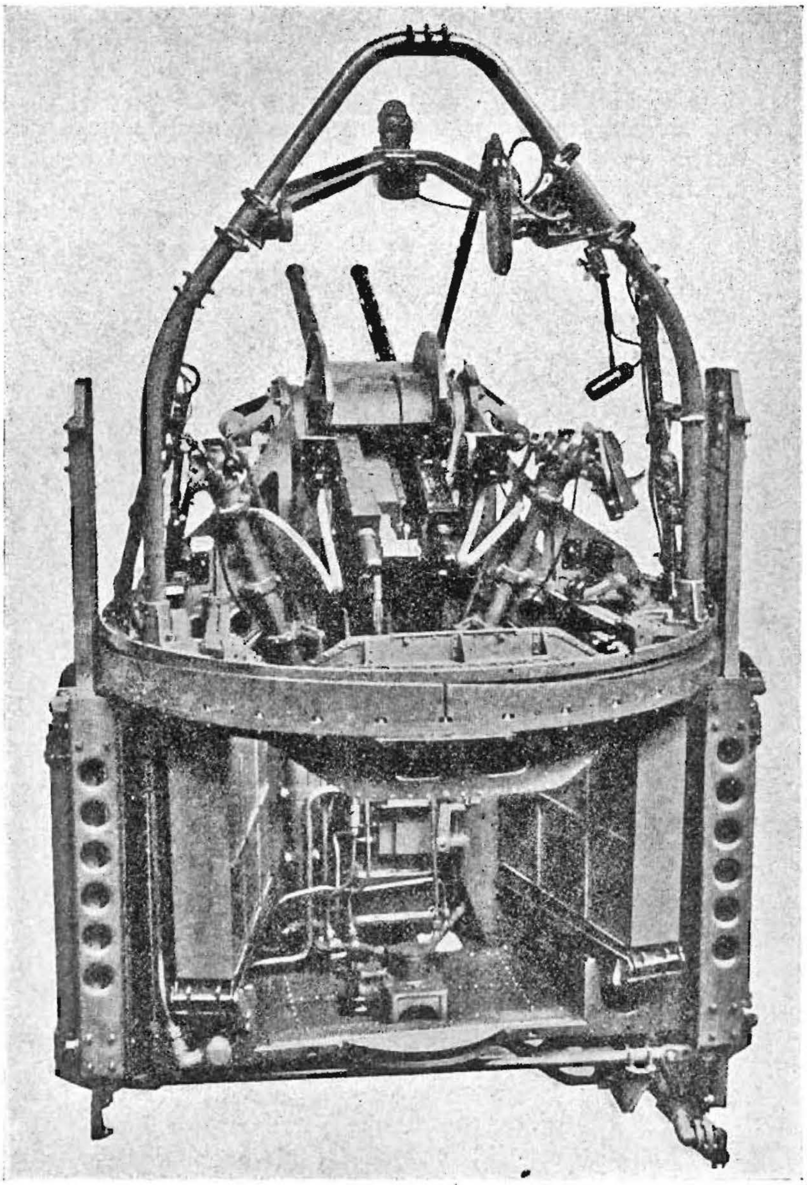
Prior to 1939, Frazer Nash Ltd., produced three upper-turrets, namely the FN. 1, FN. 7 and FN. 8.

FN. 1 Turret.—This turret was produced for a two-seater fighter aircraft. The original version was fitted with a telescopic cowling to shield the gunner, but this was replaced by a cupola later. It carried one ·303 calibre Lewis gun, fed by ammunition in pans, and the gun was fired by a simple cable device. Otherwise the turret had a normal FN. hydraulic system and was introduced in 1937.[2]

FN. 1 Upper Turret Fitted with Telescopic Cowling

[1] A.M. File S.44412.　　[2] A.P. 1659A Vol. 1, Chapter 3.

FN. 7 and FN. 8 Turrets.—These were slightly different versions of the same turret; one for bomber aircraft and the other for a flying boat. The major difference was that the latter could be retracted into the aircraft hull by means of a hand pump and hydraulic rams. They carried two ·303 calibre Browning guns and used a normal FN. hydraulic system. They were introduced in 1939.[1]



FN. 8 TURRET
(WITH CUPOLA REMOVED)

Operational requirements

Upper turrets became a definite requirement in 1940, after the meeting of the Air Fighting Committee which reviewed the heavy aircraft defence policy.[2]

[1] A.P. 1659A Vol. 1, Chapter 9.

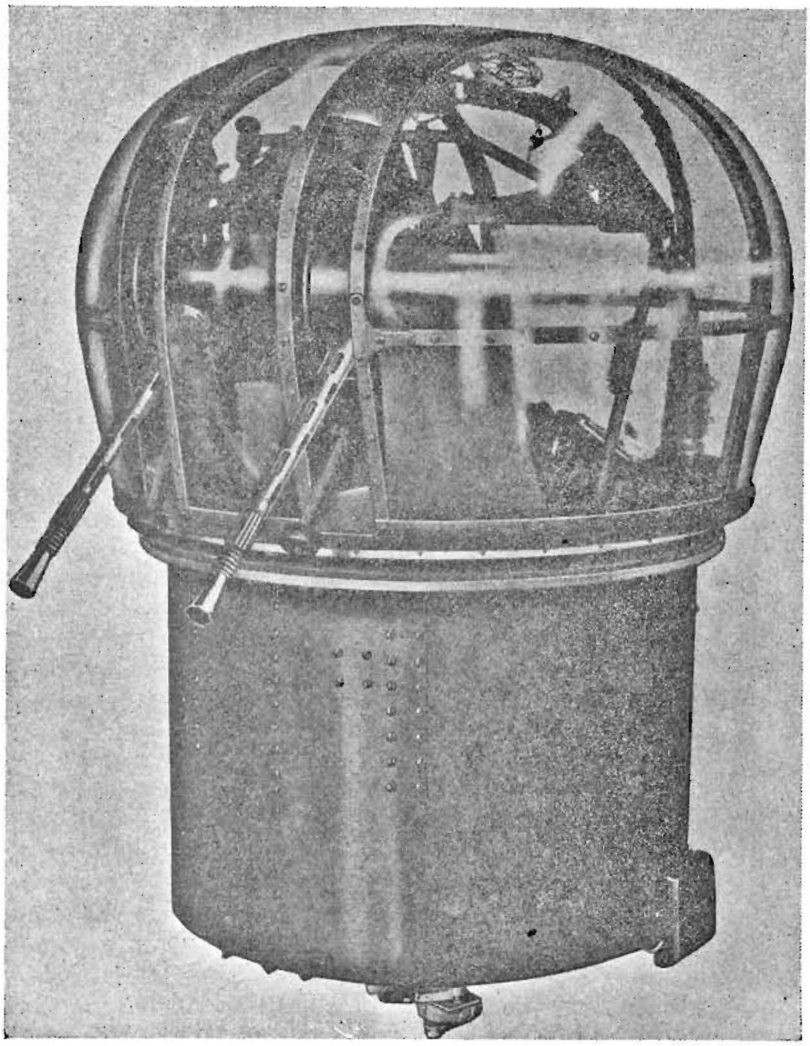
[2] 'Tail Turrets—Operational Requirements.'

The decision to replace nose and tail turrets, by fitting heavily armed upper and under turrets, was contested by a prominent member of the Scientific Staff but the Air Fighting Committee confirmed the policy to be pursued throughout the war, as follows:—

(*a*) Upper turrets would definitely be required on heavy aircraft, if the enemy developed beam and quarters attacks.

(*b*) Upper turrets carrying guns of 20-mm. calibre, were considered necessary to combat fighters carrying guns of equal calibre. It was accepted that larger calibre guns could not be fitted in tail turrets.

(*c*) When heavily armed upper turrets became available, nose and tail turrets would have to be deleted as the added weight would not be justified.[1]

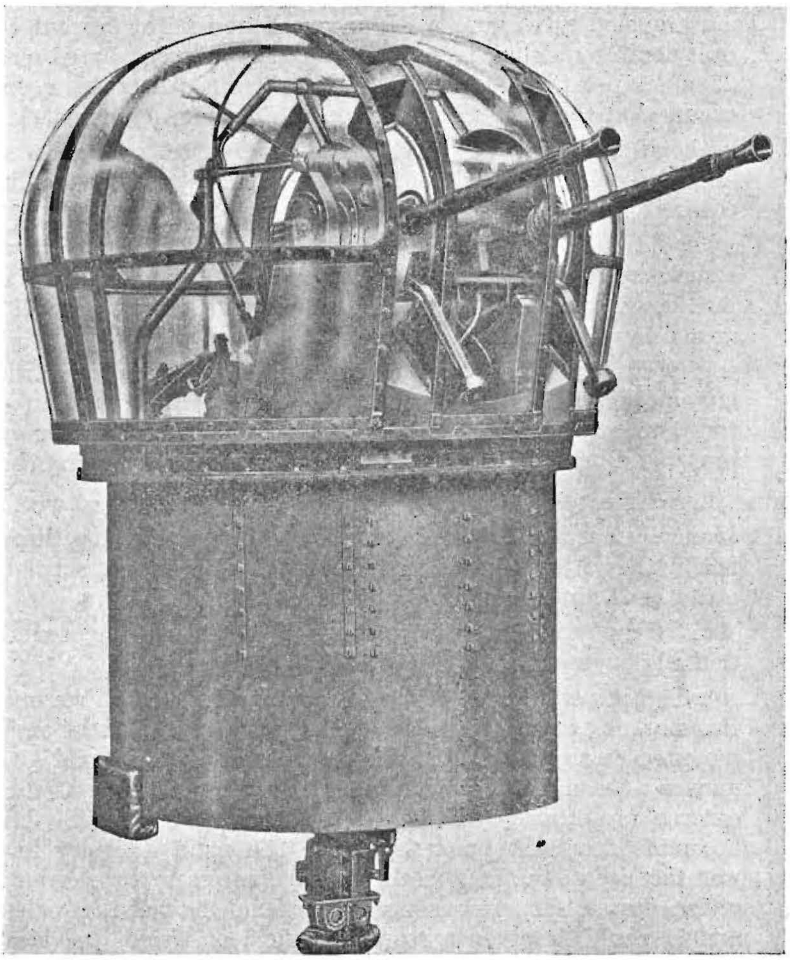


FN. 50 Upper Turret

[1] A.M. File S. 3486.

During the years 1941 and 1942 every effort was made to implement this policy. Several new upper turrets were designed and experimented with, but only two of these are worthy of note. The FN. 33, carrying four ·303 calibre Browning guns, was developed to the prototype stage but had to be abandoned as unsound, aerodynamically ; it was too heavy, had too large a ring diameter for conventional aircraft, and insufficient depression on the beam. The second, the FN. 79, carried two 20-mm. calibre Hispano guns and twelve of them were tested on operations by Bomber Command. They were found to be unsuitable for night operations, so production ceased and a standard, two-gun, upper turret, was produced and issued for service. This was an adaptation of the old FN. 5 and was named the FN. 50.[1]

FN. 50 Turret.—This turret was similar in every way to the FN. 5 except that it was modified to permit full rotation, and the guns were fired by electro-hydraulic means. It was introduced before the end of 1941,[2] and was replaced in 1944 by the FN. 150.



FN. 150 Upper Turret

[1] A.M. Files B.101099, H.S. 68053 and S. 87425. Also M.A.P. File S.B. 6103,
[2] A.P. 1659A Vol. 1, Chapter 16.

FN. 150 Turret.—The FN. 150 was a modified version of the FN. 50. The design, and gunner's field of vision, were greatly improved by the removal and repositioning of minor components. A gyro gunsight was fitted and at a later stage the radar attachment was added.[1]

Under turrets

Early Development.—The development of under turrets dates from 1936, as in the case of the types already mentioned. They were considered to be necessary to cover the inevitable 'blind spot' below an aircraft, resulting from the limits of the arcs of fire of the other turrets. It was felt that if this area was left undefended, the enemy would concentrate on this weak spot in the defence system and evolve some form of attack. Early research soon showed that the decrease in aircraft performance, resulting from a turret projecting downwards into the air stream, was prohibitive but there appeared to be no other solution to the problem of downward defence. A review of the aircraft defence policy in December 1937, produced the following summary of the advantages and disadvantages, of retractable under turrets :—

(*a*) They provided extra guns, with an excellent field of fire but offered considerable resistance, reducing the aircraft speed by as much as 25 miles per hour (approximately 18 per cent.). This reduction occurred at the least desirable moment, *i.e.*, during an attack.

(*b*) They could be designed to give the gunner an excellent field of search and reasonable personal comfort but, when retracted, they limited the crew space available within the aircraft fuselage.

(*c*) They could be used to reinforce the nose and tail turrets, or to afford a measure of protection should these turrets be put out of action but, however carefully designed, there would still be a small blind area below the under turret itself.

(*d*) Being positioned amidships, they could carry large quantities of ammunition without upsetting the centre of gravity. An under turret plus the necessary retraction gear, however, was abnormally heavy and hence, ammunition weight had to be a compromise.

Possible alternatives which had been, or were being, investigated were :—

(*a*) A manually operated gun mounting with the gun(s) firing through a hole in the bottom of the aircraft fuselage. This was not satisfactory, owing to the limited arc of fire and field of vision.

(*b*) A fixed front gun backed by a manually operated gun, covering a limited downward arc.

(*c*) A rotating, power operated disc, mounted on the floor of the fuselage, transparent as far as possible and with the gunner's seat and guns mounted at the centre. It was expected that this would give the gunner a reasonable view and offer little air resistance, as the only external projections would be the gun barrel(s), and a small 'blister' accommodating the gunner's feet. The main difficulty foreseen was the size of the hole in the fuselage necessary to accommodate a disc of useful dimensions, bearing in mind the fact that unless the gunner could be given a reasonable field of vision, the idea was redundant.

[1] A.M. Files S. 98887 and C.S. 23680. Also M.A.P. File R/S.B. 55690/2. *See* A.P. 2799H. Vol. 1.

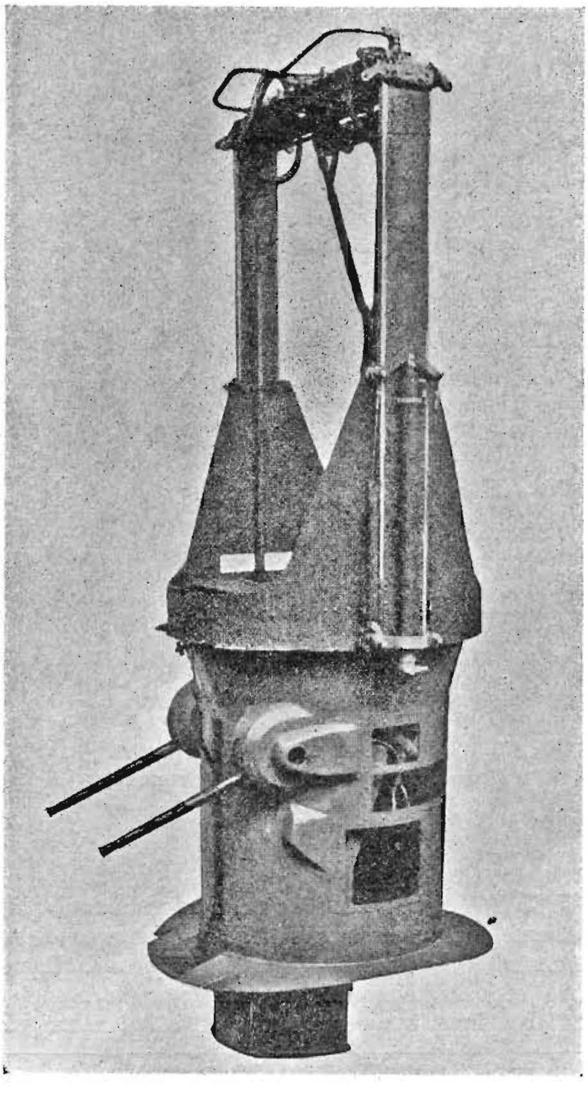
After due consideration, the Air Ministry made the following decisions :—

(a) Retractable turrets were to be retained on large aircraft, until something better could be devised.

(b) Research work on 'dragless' under turrets, along the lines of the idea mentioned in paragraph (c) above, was to continue on a high priority.[1]

Prior to 1939, Frazer Nash Ltd., produced two power operated under turrets for heavy bomber aircraft, and two hand operated under mountings for lighter aircraft, namely, the FN. 17, FN. 25, FN. 54 and FN. 60.

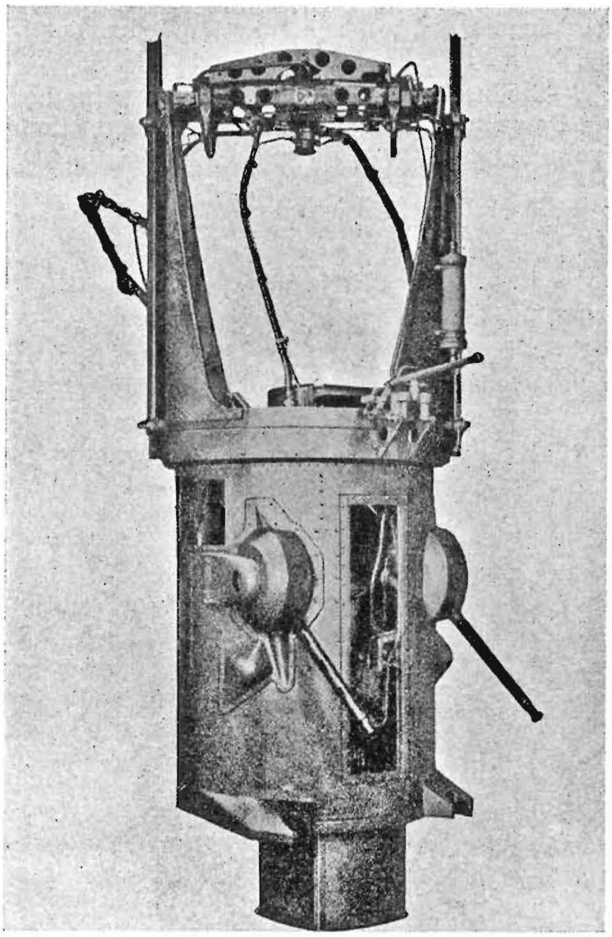
FN. 17 Turret.—Produced for a heavy bomber aircraft, this turret carried two ·303 calibre Browning guns and apart from the retraction gear, it was a normal FN. hydraulic unit.[2]



FN. 17 UNDER TURRET
(RETRACTION GEAR FULLY EXTENDED)

[1] A.M. File S. 44249.
[2] A.P. 1659A Vol. 1, Chapter 7.

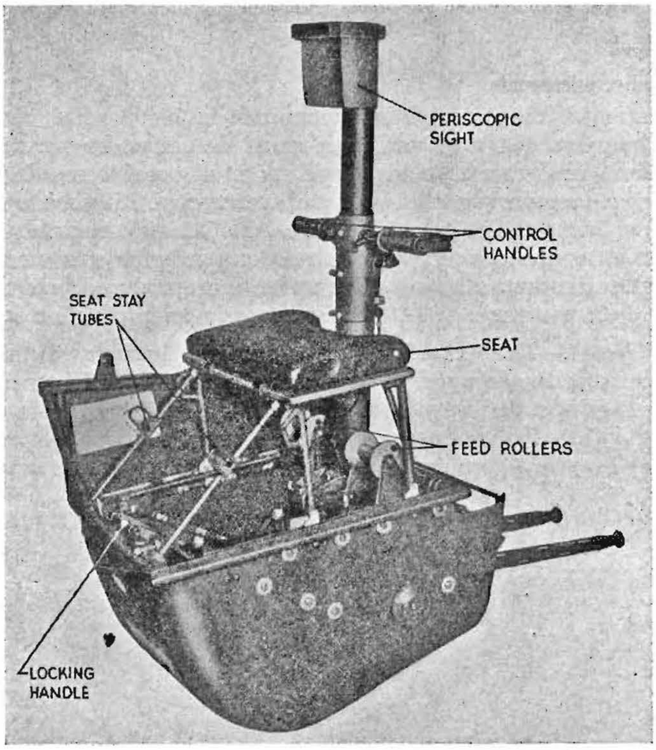
FN. 25 Turret.—This turret was similar to the FN. 17 in all respects and was fitted to two different types of heavy bombers.[1]



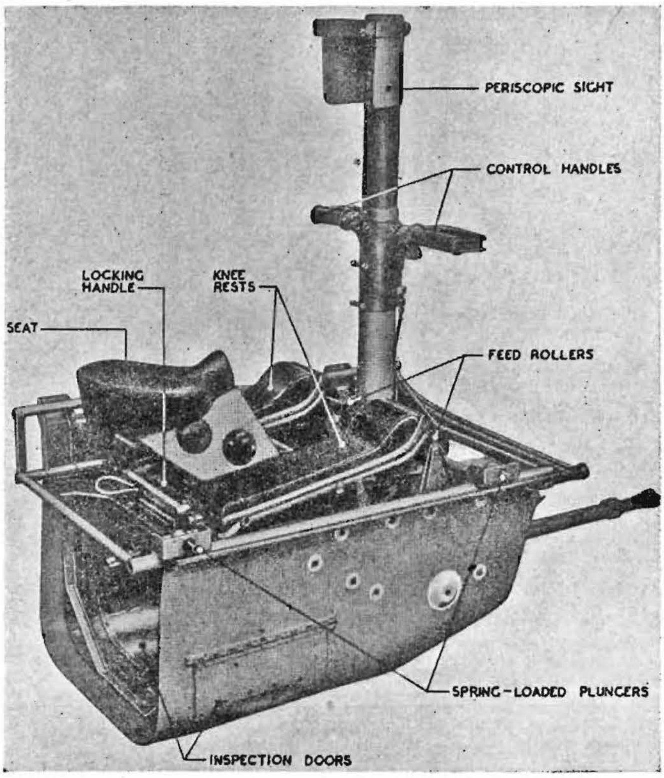
FN. 25 UNDER TURRET
(RETRACTION GEAR FULLY EXTENDED)

FN. 54 and FN. 60 Turrets.—These were non-retractable, hand operated, under gun mountings. They were similar in all respects apart from the gunner's seating arrangements. A periscopic sight was used on both mountings and the units could be jettisoned complete, to provide an emergency escape hatch. They were fitted to a light bomber aircraft with limited crew space.[2]

[1] A.P. 1659A Vol. 1, Chapter 12. [2] A.P. 1659A Vol. 1, Chapter 15.



FN. 54 TURRET

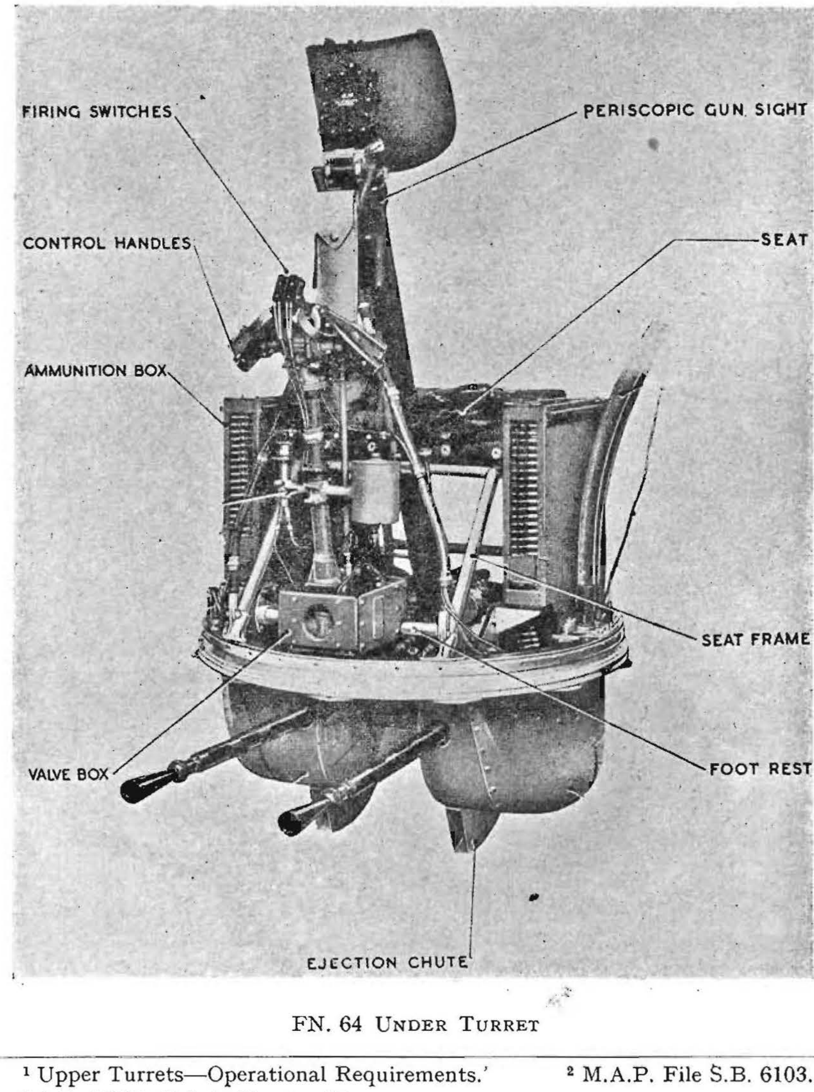


FN. 60 TURRET

Operational requirements

The meeting of the Air Fighting Committee in 1940,[1] which outlined the policy to be pursued during hostilities, specified that under turrets, carrying heavy calibre guns, were to be developed with all possible speed. However, during the time required for this work, tail turrets were still the major requirement and, as time was also being devoted to an all electric, remotely controlled turret system as the complete solution to current problems, under turrets received little attention. The only other under turret produced, before hostilities ceased in 1945, was the FN. 64. This was ready for production in 1941.[2]

FN. 64 Turret.—This turret was a compromise between the retractable under turret, and the ' dragless ' turret actually required. In general design, it was a power operated version of the FN. 54 and FN. 60. The sight was periscopic and hence, the turret was not very useful at night. It carried two ·303 calibre Browning guns and employed normal FN. hydraulic components.[3]



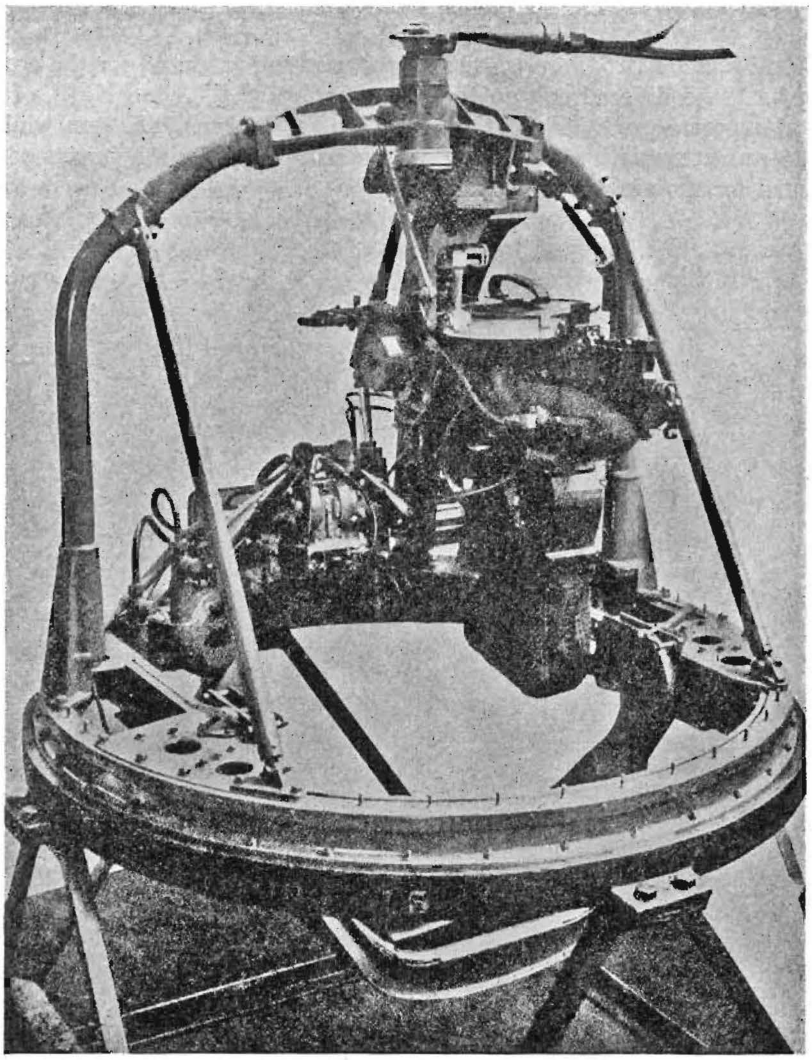
FN. 64 Under Turret

[1] Upper Turrets—Operational Requirements.' [2] M.A.P. File S.B. 6103.
[3] A.P. 1659A Vol. 1, Chapter 17.

Nose turrets

Early Development.—Nose turrets were introduced as part of the general aircraft defence policy of the Air Ministry in 1936.[1] The requirement was again confirmed by the policy review in 1937,[2] but the further review in 1938,[3] recommended that they should be deleted in favour of heavy calibre upper and under turrets, should these become available.

Prior to 1939, Frazer Nash Ltd., produced six nose turrets for heavy bomber aircraft or flying boats, namely, the FN. 5, FN. 11, FN. 12, FN. 14, FN. 16 and FN. 26.



FN. 11 NOSE TURRET
(WITH CUPOLA REMOVED)

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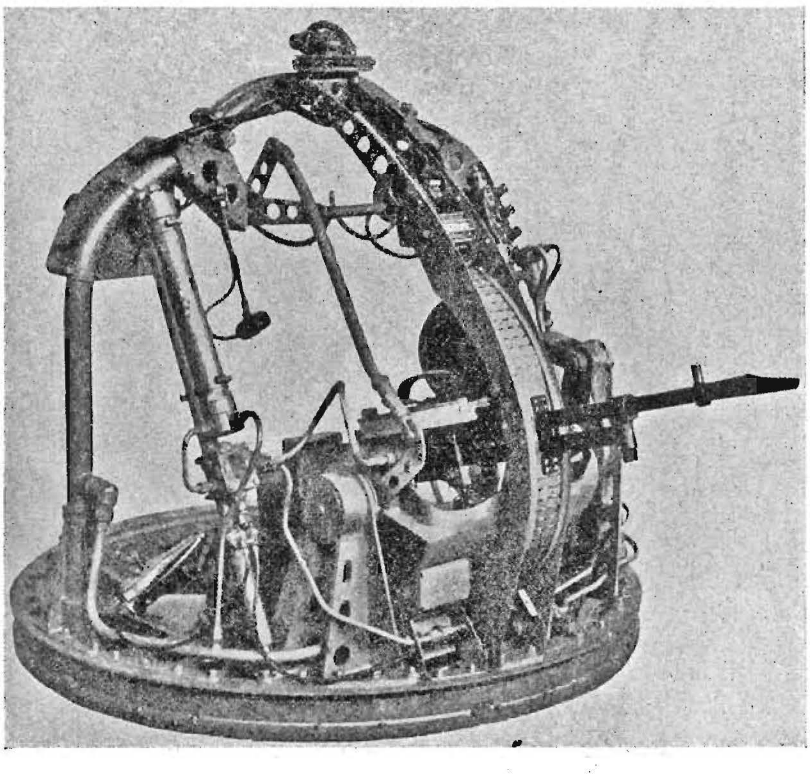
[1] A.M. File S. 38527. [2] A.M. File S. 44249. [3] A.M. File S. 44412.

FN. 5 Turret.—This turret has already been mentioned in the section devoted to tail turrets. It was used in the nose and tail of one type of aircraft and in the nose of two others. The different versions varied in small technical details only, such as ammunition arrangements and cupola design.[1]

FN. 11 and FN. 16 Turrets.—The FN. 16 was produced for a heavy bomber aircraft and carried one ·303 calibre Vickers Gas Operated gun (VGO), which was pan fed, like the Lewis gun. The FN. 11 was fitted in the nose of a flying boat and was identical with the FN. 16, except that it was mounted on guide rollers fitted to the hull structure. A hand winding device enabled the turret to be retracted on the guide rollers, for mooring operations.[2]

FN. 12 and FN. 26 Turrets.—These turrets were produced for the nose of a flying boat and differed only in the type of gun fitted. The FN. 12, of which only a few were produced, carried a twin, ·303 calibre, VGO gun whilst the FN. 26 was fitted with a single gun, of the same make. Both turrets could be retracted for mooring operations.[3]



FN. 26 Nose Turret
(with Cupola removed)

[1] A.P. 1659A Vol. 1 Chapter 11.
[2] A.P. 1659A Vol. 1 Chapter 5.
[3] A.P. 1659A Vol. 1 Chapter 8.

FN. 14 Turret.—This turret has already been mentioned as the FN. 15 tail turret. The two versions varied in small technical details only apart from the fact that the nose turret carried one ·303 calibre Lewis gun, instead of two. The position for the second gun was occupied by a bombsight.[1]

Operational requirements

The pre-war policy of producing nose turrets as an interim measure, until heavy calibre upper and under turrets became available, persisted throughout the period of hostilities. In June 1942, the Air Fighting Development Unit at Duxford, suggested that nose turrets were no longer required by modern bomber aircraft as tactical trials, of all current types, had proved that head-on attacks could easily be dealt with by manœuvre and upper turrets. Bomber Command, however, stated that although nose turrets were not required for night operations they were still essential in daylight. Furthermore, they were expecting a marked increase in daylight sorties and hence, the Air Ministry decided that nose turrets were to be retained. Permission was given for turrets to be 'blanked-off,' either by detachable fairings or doped patches, as required.[2] No new nose turrets were produced between 1939 and 1945, but the FN. 5 was treated as a standard product and was adapted for use in several different aircraft.

Miscellaneous products

In addition to the power operated turrets described above, Frazer Nash Ltd. produced two other items of interest as aircraft armament. One was the FN. 77 turret or 'Leigh Light,' and the other was a series of hand operated gun mountings, for use where low aircraft speeds, weight saving and tactical requirements made them both desirable and possible.

FN. 77 Turret.—During the early stages of the war, anti-submarine operations at night met with little success. A suggestion was made that a powerful searchlight should be fitted to anti-submarine aircraft, in order to make night identification and attack possible. After prolonged research and experiment, the Leigh Light[3] or FN. 77 turret, was produced and came into service in 1942.[4] Briefly the device consisted of a twenty-four inch naval searchlight, mounted in a retractable under turret, and controlled from the nose of the aircraft through the medium of normal FN. control handles and other hydraulic components. In the first place Frazer Nash Ltd. adapted an FN. 25 under turret for this purpose, but this was replaced later, by a production model, known as the FN. 77.[5]

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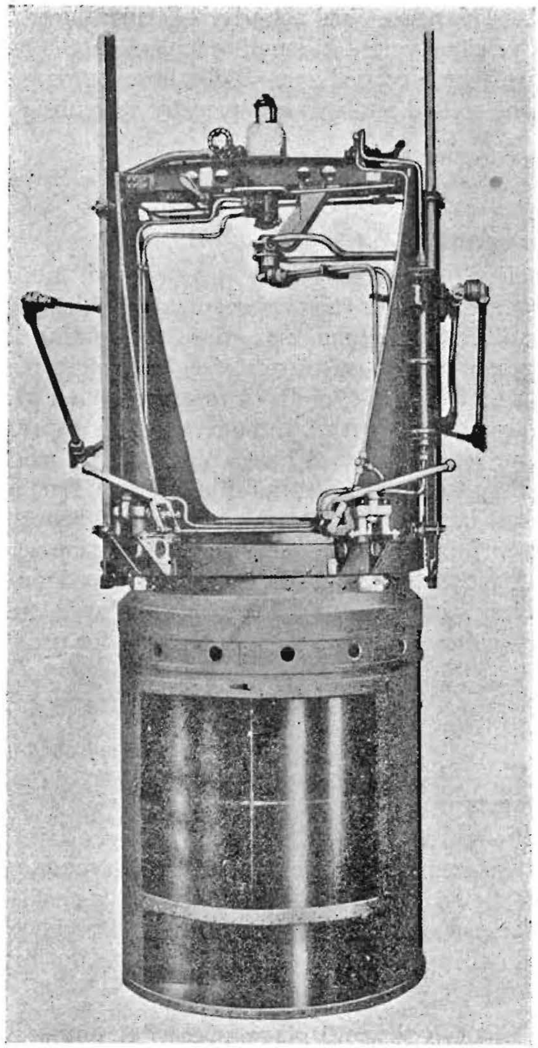
[1] A.P. 1659A Vol. 1 Chapter 4.

[2] A.M. File C.S. 16940.

[3] Named after the Royal Air Force officer who suggested and developed the scheme.

[4] M.A.P. File S.B. 55700/2.

[5] For further details *see* Appendix 2.



FN. 77 TURRET

Hand operated gun mountings

Frazer Nash Ltd., produced a number of hand operated mountings, in addition to those already mentioned, *i.e.*, the FN. 54 and FN. 60. They were particularly useful in aircraft of Coastal Command for anti-submarine work, etc., and in addition to being a satisfactory weapon, they provided a great saving in weight and helped to simplify the equipment carried. Normally they were used as nose or beam mountings.[1]

[1] A list of hand operated mountings will be found in Appendix 1.

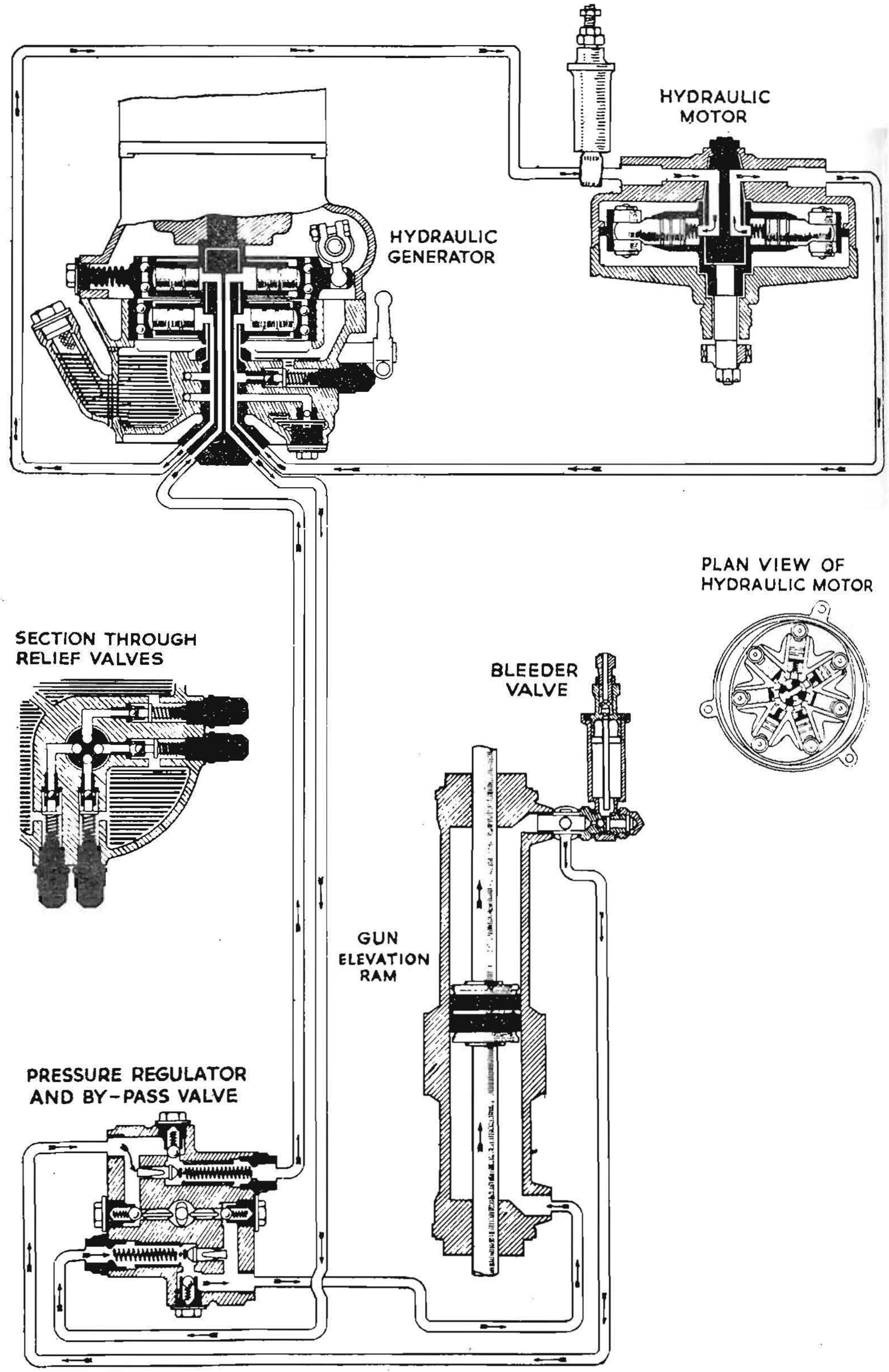
CHAPTER 15

BOULTON PAUL TURRETS

The turret system developed by Messrs. Boulton Paul was electro hydraulic in which an electric motor was coupled to a double, variable stroke, hydraulic pump. One unit of this pump working at a pressure of 1,200 lb. per square inch, fed a cam type hydraulic motor which was coupled through suitable gearing to the turret ring to provide rotation. The other pump working at 750 lb. per square inch, was coupled to a double acting hydraulic ram for gun elevation and depression. Some types of turret dispensed with the rams and used a second hydraulic motor.

The turret control consisted of a switch mounted on the front panel in the turret, which, when turned 'ON' energised the field circuit of the electric motor, but did not start the motor until another switch, incorporated in the control handle, and known as the 'deadman's handle,' was depressed. The control column which was connected to both units of the double pump, controlled the stroke of the piston and consequently the output of the pumps, and speed of rotation and elevation. Movement of the control handle forward operated the elevating pump giving depression of the guns, whilst a backward movement reversed the pump flow and gave elevation. Similarly right or left hand deplacement of the control handle operated the rotation pump and gave right and left hand rotation. Progressive control column displacement gave a progressive speed change and a combination of both rotation and elevation was obtained by angular movement of the control, but it was not possible to have maximum elevation and rotation speeds together to avoid overloading the power unit.

Higher speeds, approximately twice normal, were available by depressing a button adjacent to the control column. This functioned by introducing a resistance into the electric motor field circuit. Safety valves were fitted in the hydraulic circuit to avoid damage to the turret mechanism should there be some obstruction to the movement of the guns. A 'free' device was provided so that the turret could be rotated or guns elevated manually. The electrical supply was taken into the turret via slip rings and brush gear, provision also being made for subsidiary electrical services. There were no rotating pipelines as the whole hydraulic system was self contained in the turret. The sight corrector mechanism was chain driven from the hydraulic motor gearing which provided the drive for turret rotation, provision being made for chain adjustment. This same chain drove the fire interrupter drum.



B.P. TURRET—HYDRAULIC SYSTEM

Boulton Paul Marks I and II

A two seater fighter had been designed by Messrs. Boulton Paul which was to be fitted with a four gun turret amidships and flight trials of the aircraft were expected to be carried out early in 1936. The aircraft designer had discussed proposals for a mechanically operated turret, with the Assistant Director of Armament Research and Development (AD/R.D.ARM) of the Air Ministry.[1] The turret proposed was manufactured by the Societe D'Applications des Machines Motrices of Paris, early turrets being known as the S.A.M.M. turret. The aircraft designer had examined and handled the turret on the ground and was of the opinion that the control was as good as, if not superior, to that offered by the Frazer Nash Demon turret. He had obtained an option on the turret which was due to expire, and he felt disinclined to negotiate for the turret in view of the fact that he had not, at that time, a contract to build the aircraft. The Director of Technical Development (D.T.D.) of the Air Ministry agreed to the purchase of the turret as it was felt that it would be very valuable to have one for trials with the option of future manufacture in this country.

Several modifications were necessary to the S.A.M.M. turret before it was suitable for service use. A prototype was fitted in the nose of an Overstrand aircraft to carry out firing trials which took place in July and August 1937. In February of the next year tests were successfully carried out in the Defiant aircraft.[2] During these trials it was found that the electric generator installed in the aircraft was severely overloaded and to ensure reliable operation of the turret it was necessary to change the accumulator between flights. The electrical circuit was modified so that the main current was taken direct from the aircraft generator; this made it impossible to operate the turret when the aircraft engine was not running, but by providing a plug which could be connected to high capacity engine starter batteries, this disadvantage was overcome.

To preserve a good air flow over the aircraft, fairings were fitted in front of and behind the cupola. These were operated by a pneumatic mechanism which was brought into operation automatically as the turret rotated, and the fairings were retracted to prevent the guns hitting them. The compressed air bottle was replenished by an engine driven compressor, and early in the trials it was evident that the compressor could not build up the pressure quickly enough, and if the turret was used to any great extent, there was a danger of failure of the wheel brakes on landing as these were fed from the same air bottle. A more powerful compressor was fitted early in 1940.[3] Other protective devices were fitted to provide against the following contingencies :—

(*a*) Firing ceased automatically when the line of fire of the guns approached interfering portions of the aircraft.

(*b*) When the turret was mounted centrally in the aircraft an interlock device was fitted to prevent fouling of the gun barrels on the adjoining fuselage.

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[1] A.M. File S.36156. [2] M.A.P. File R/S.B. 2182 Part I.

[3] Aircraft Equipment Committee 110th meeting.

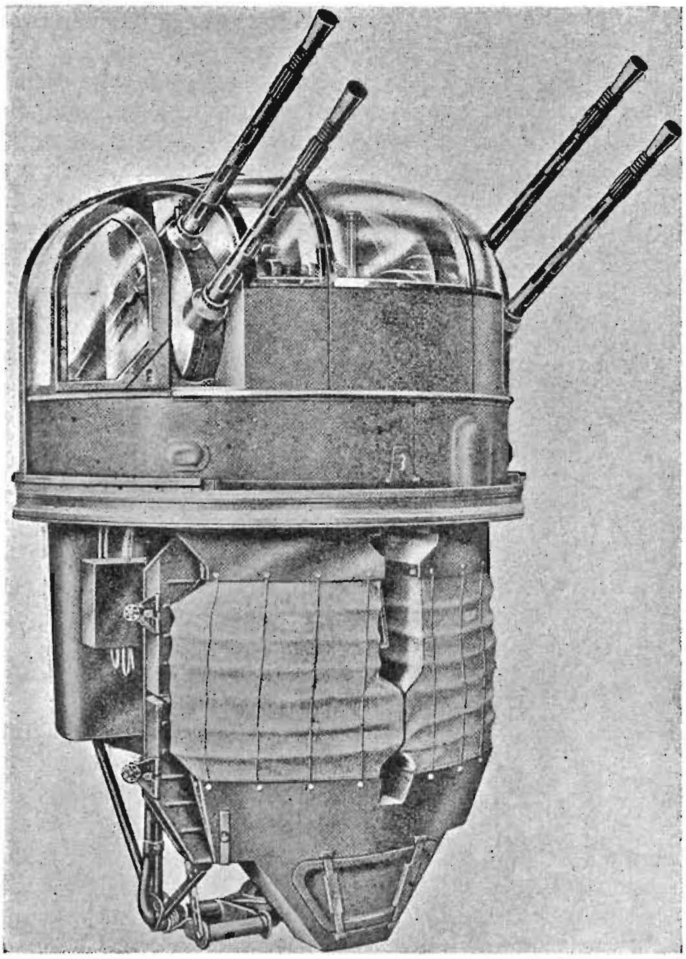
The turret at that time had been made to Air Staff requirements of 360 degrees rotation and 84 degrees elevation with no depression. Tactical trials showed that it was desirable to have some depression on the guns when attacking an aircraft near the ground. A maximum of 10 degrees depression could be obtained without extensive modification, but the angle of elevation had to be reduced by a similar amount. The provision of 10 degrees depression meant that a two stage interlock mechanism would have to be provided to prevent the guns striking the fuselage both in the front and rear of the turret. The existing interlock was only single stage and operated over the forward fairing. One part of the mechanism limited the depression of the guns while they were over the obstruction ; the other part limited rotation when the guns were clear of the obstruction, but were depressed below the angle which would cause them to foul the obstruction. No interlock was required aft because when the guns were horizontal they came down on to a stop and in this position cleared the fuselage. The manufacturers investigated the problem and were of the opinion that it would involve a major re-design of parts and would take some time to develop the two stage interlock.

Upper turrets

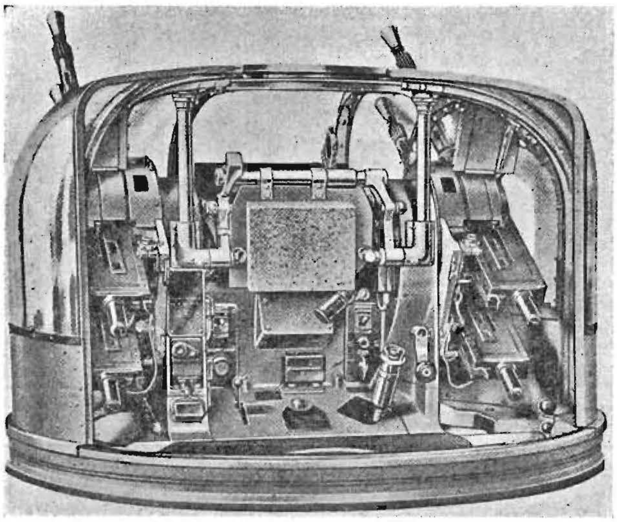
Boulton Paul Type ' A ' Turrets.—The original basic design of turret fitted with four ·303-inch Browning guns, was known as the Mark I for the basic design and Mark II for the design eventually issued to the Service in October 1938. The latter mark had a suffix letter after the number to indicate the type of aircraft to which it was fitted. Marks III, IV and V were similar to the Mark II, but had minor differences to enable them to be fitted to specific aircraft.[1] In addition in the Mark V a remote control fire disengaging gear was provided to enable the turret to be uncoupled from the hydraulic system from a position inside the aircraft. The Mark VI retained the disengaging gear, but had a different range of gun travel and movement below the horizontal was introduced, the cupola being suitably modified to accommodate the altered elevation movement.

In order to increase the fire power of heavy bombers[2] a four gun turret was designed to replace the Type ' C ' Mark V which had two ·303 Browning guns. This turret known as the Mark VII[3] was not produced, but as it was similar to the Mark II, of which there were many surplus to requirements, the surplus stocks were modified, and after modification were known as the Mark VIII (special) being introduced into the Service in January 1943. The Mark VIII (standard) turret had a field of fire of 74 degrees elevation and $2\frac{1}{2}$ degrees depression, whilst the special retained the Mark II field of fire. In September 1943, stocks of the Mark VIII special had been used up and the Mark VIII standard was fitted to aircraft on the production line.[4]

[1] A.P. 1659 C, Volume I.
[2] Air Staff Policy has been dealt with in Chapter 14.
[3] M.A.P. File R.A. 2295.
[4] A.M. File H.S. 68409.

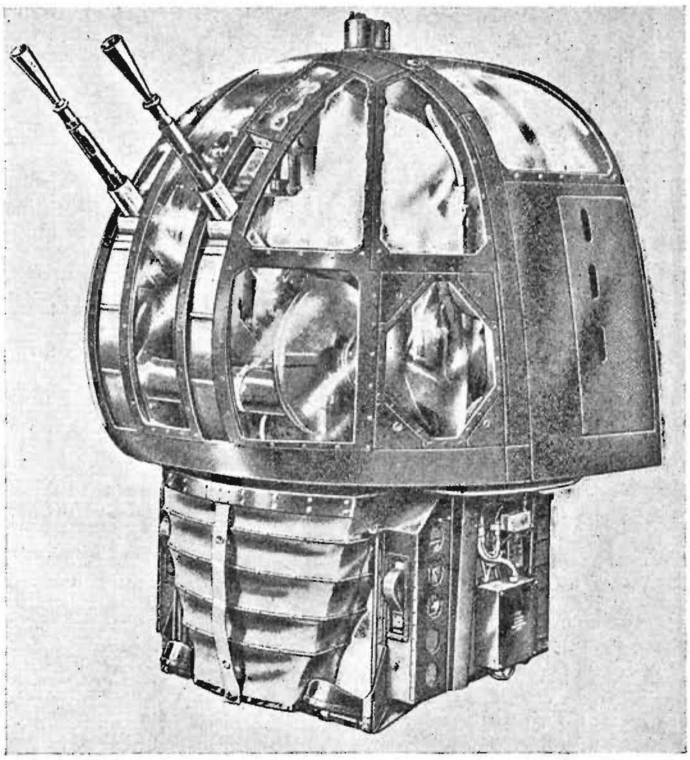


B.P. Type 'A', Mark III Turret



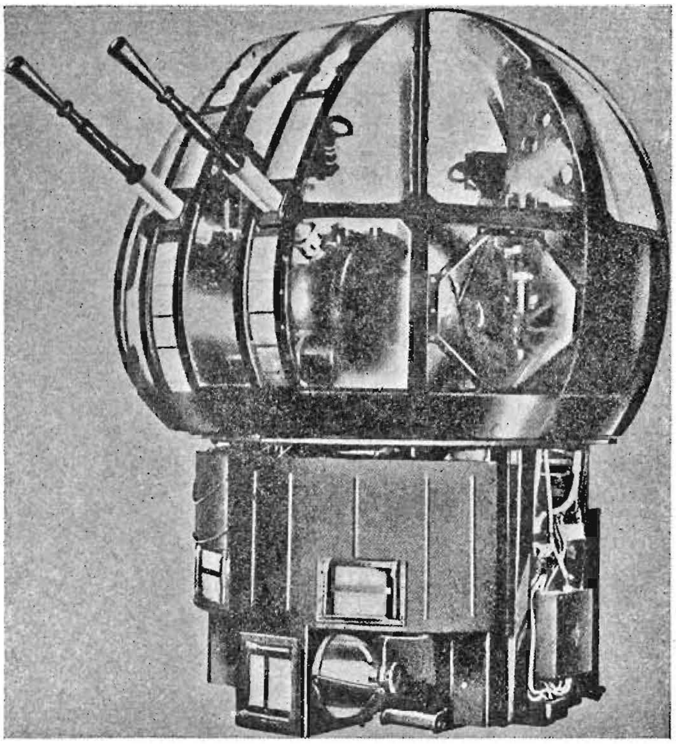
B.P. Type 'A', Mark III Turret—Interior View

Boulton Paul Type 'C' Turrets.—These turrets were fitted with two ·303-inch Browning guns. The first type made—the Mark I—was used as a nose turret for heavy bomber aircraft, and had a field of fire of 100 degrees each side of the aircraft centre line and 64 degrees elevation, 45 degrees depression. Subsequent Marks had continuous rotation, retaining the original elevation and depression angles. In this condition they were used as upper turrets in heavy bombers and general reconnaissance aircraft. Also the oxygen supply was self contained in the turret, whereas in the Mark I the gunner was supplied from the main aircraft supply. Other types of turret were designed for use in the upper position, but were not introduced for service use before the cessation of hostilities.[1]



B.P. TYPE 'C', MARK I TURRET

[1] List of B.P. turrets is given at Appendix 4.



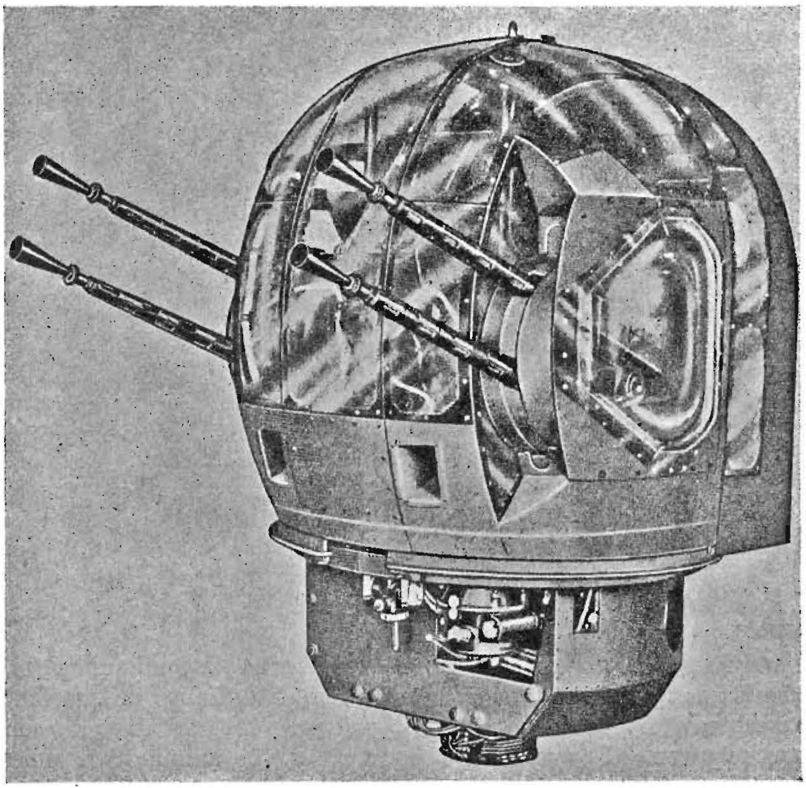
B.P. Type 'C', Mark II Turret

Tail turrets

The weight of tail turrets had to be kept down to a minimum in order to keep the aircraft centre of gravity within permissible limits, and as the tail of the aircraft was the most vulnerable position, it was here that the most ammunition was required. To overcome this difficulty, the ammunition boxes were placed inside the aircraft and the ammunition was fed through long channels or ducts to the guns. As the normal loading action of the gun was insufficient to pull the long length of belt, feed assisters were used to feed the ammunition to the guns.

Boulton Paul Type 'E' Turret.—This turret was designed for use in heavy bomber aircraft and had four ·303-inch Browning guns with 2,500 rounds of ammunition per gun. The field of fire on the Mark I was 90 degrees each side of the centre line of the aircraft ; early models had 60 degrees elevation, later 56½ ; and 50 degrees depression. The feed assisters on this turret were housed in the turret framework being driven by a chain drive from the electric motor which drove the generator. The speed of operation of the assisters was automatically regulated by the tension in the belts between the feed assister and guns. In this turret the high speed switch was deleted.

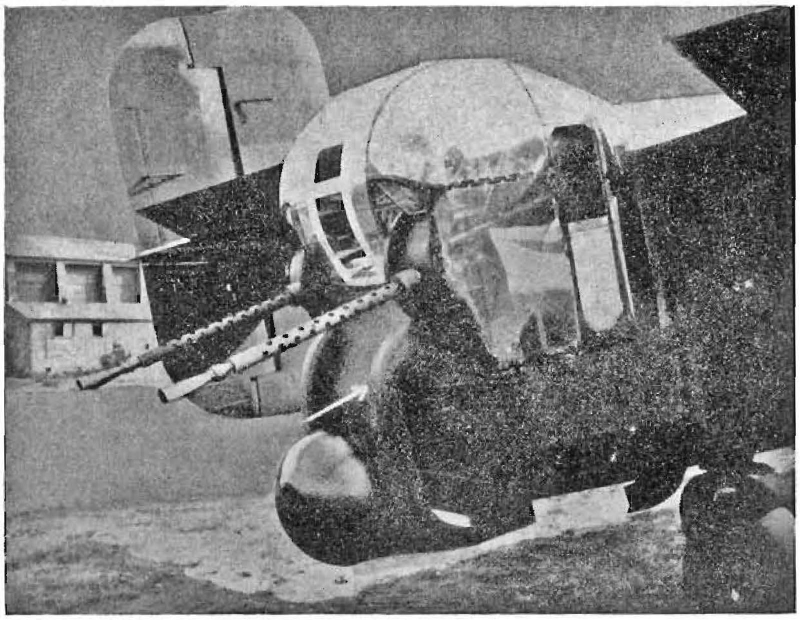
Owing to the large angle through which it was possible to depress the guns, the gunner's seat was coupled to a hydraulic ram, connected in series with the gun elevating ram in such a way that when the guns were at full depression, the seat was at its highest. A later series of turret had a clear vision panel in which the front perspex panel was arranged to slide out of the way for use when weather conditions made sighting through the transparent panel difficult. In the Mark II turret of this type, the rotation was limited to 65 degrees each side of the aircraft, and the ammunition supply was altered to suit another type of heavy bomber. Production of these turrets ceased in 1944 in favour of the larger calibre turret—the Type ' D '.



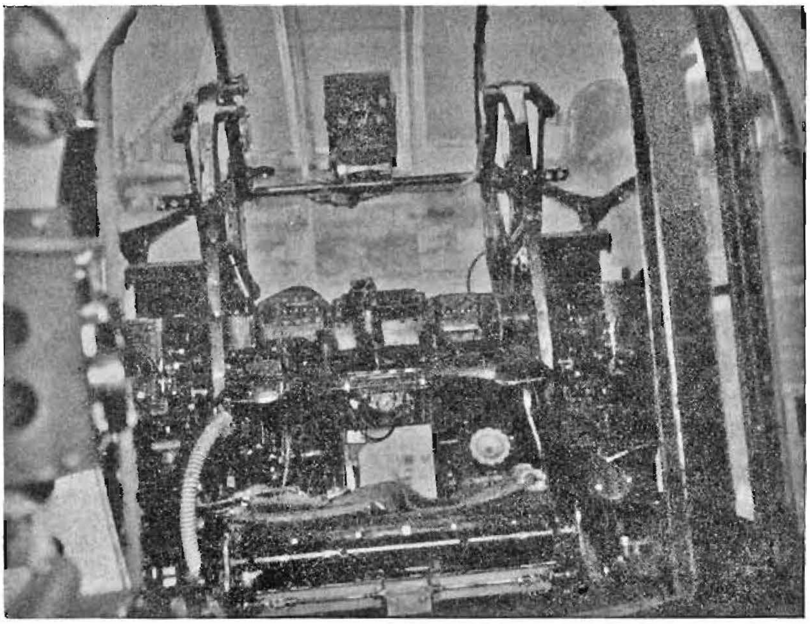
B.P. TYPE 'E' TURRET

Boulton Paul Type ' D ' Turret.—In December 1942, a programme was drawn up to improve the armament of heavy bombers, in which two ·5-inch guns were required in the tail. Boulton Paul's had a scheme for modifying the Type ' E ' to take two ·5-inch guns, and it was considered that the weight could be kept down to the existing limits provided that a reduction in the amount of ammunition carried in the turret could be accepted. At least 1,500 rounds per gun was required, but if this was not possible for centre of gravity reasons, less would be considered as long as the supply could be topped up from inside the aircraft.

The first prototype turret, known as the Type ' D ' was ready for test in October 1943. Each ammunition duct had two electrically operated feed assisters. In this turret hydraulic motors were provided for both rotation and elevation ; mechanical stops being provided at the limits of rotation and elevation. It was anticipated that this turret would be used in conjunction with

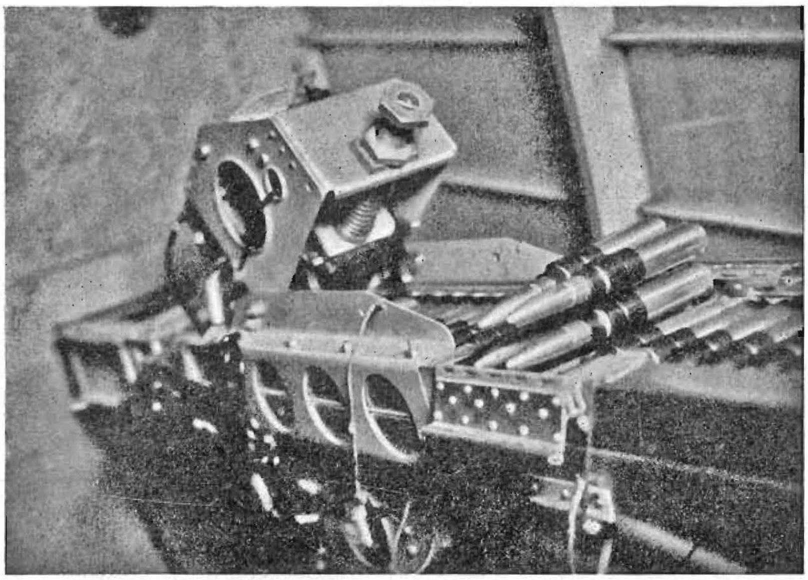


External View

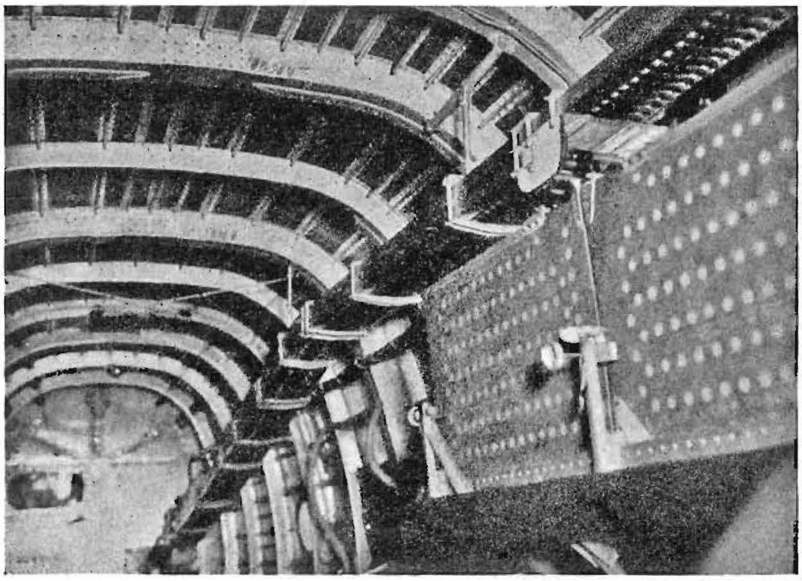


Interior View

B.P. Type 'D', Mark II, Turret in Halifax Mark III Aircraft



Feed Assister



Ammunition Ducts

B.P. Type 'D', Mark II, Turret in Halifax Mark III Aircraft

A.G.L.T.,[1] and the Mark I of the type was manufactured with that object in view. When the turret had the scanner incorporated it was named Mark II. The guns were capable of 45 degrees above and below the horizontal, and during the tests, the possibility of having 60 degrees depression was investigated, but re-design would be necessary. The turret was introduced into the Service in September 1944 to replace the Type 'E.'

Nose turrets

The first nose turret designed by Boulton Paul was the Type 'C' Mark I fitted with two ·303-inch Browning guns, but was only used to a limited extent. Later marks were fitted in the upper position and are dealt with in that section.

Boulton Paul Type ' F ' Turret.—During 1944, a turret was required for use in heavy bomber aircraft fitted with an ideal nose. This was an observation station in the nose of the aircraft with a good field of vision all round and used by the bomb aimer. The ammunition was contained in the turret and consisted of 250 rounds per gun for the two ·5-inch Browning guns with which it was fitted; reserve supply of ammunition of 300 rounds, was carried inside the fuselage for re-arming in flight. The turret was mounted above the bomb aimer position with the controls below the turret so as to afford him full facilities for operation of the bombsight or turret alternatively from the same seat. The turret was fitted with Frazer Nash handle bar type controls as these were more easily adapted for this layout.[2] The field of fire was 45 degrees each side of the aircraft centre line and 40 degrees above and below the horizontal. The turret was introduced into the Service in August 1944.

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[1] A.G.L.T. automatic gun laying turret. Radar assisted sighting.

[2] M.A.P. File S.B. 55910/2, Part 1

CHAPTER 16

BRISTOL TURRETS

The Bristol Aeroplane Co. Ltd., started to develop and produce aircraft turrets at the same time, and under the same conditions, as the firms of Frazer Nash and Boulton Paul Ltd. The Air Ministry policy governing their activities, has been outlined in a previous chapter[1] and, broadly speaking, the progress of their development work up to the year 1945, was allied closely to that of the other leading firms. This firm differed from the others, however, in that instead of selecting a standard power system for all their production models, and improving it as experience was gained, they started with a hydraulic system and then changed over to an all electric system. Their first all-electric turret, fitted with guns of 20 mm. calibre, was in production when hostilities ceased in 1945.

Bristol turrets were identified by the initial 'B' followed by a serial number and, in addition, different versions of any one type were given a mark number, *e.g.*, B.I. Mark 1. The mark was altered both as the type was improved, or when it was adapted for use in a different aircraft.

Throughout the period covered by this history, the Bristol Aeroplane Co. Ltd., produced a limited range of turrets for operational use. Almost without exception, these were upper turrets and hence, only those which were examples of progress in design will be specifically mentioned. In addition to power operated turrets, they produced a few hand operated gun mountings of which no further mention will be made, as they were simple in design and of little technical interest.[2]

The Bristol hydraulic system[3]

The Bristol hydraulic system was very similar to that of the Frazer Nash products, in that oil was supplied by an engine driven pump and circulated through control valves, etc., back to the pump. Instead of using a hydraulic motor however, for turret rotation, the early models used a hydraulic ram. A motor had to be introduced later as the arc of rotation produced by a ram was obviously very limited. One type of turret employed two rams in order to achieve increased traverse ; one ram rotated the turret structure and the other moved the guns through an additional arc.

In many Bristol turrets, the gunners seat was linked to the gun elevating ram and moved up and down with the guns, so facilitating sighting ; in a few a separate seat ram was fitted. Where this occurred, a 'hydraulic lock' was introduced into the system, to keep the seat stationary, unless the controls were operated for elevation or depression.

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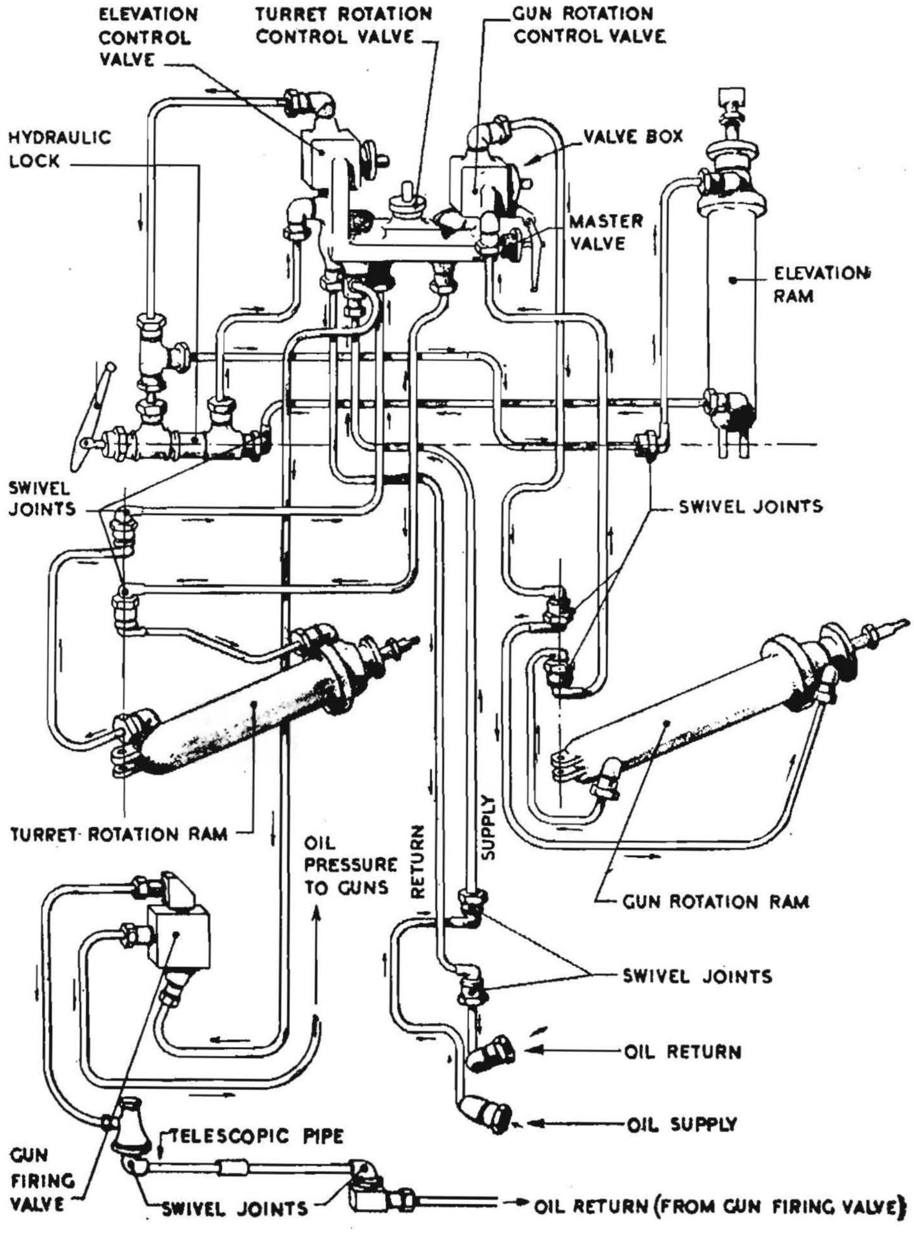
[1] For full details, *see* Chapter 14—'Frazer Nash Turrets.'

[2] A complete numerical record of Bristol turrets and gun mountings, will be found in Appendix 5.

[3] A.P. 1659B, Vol. 1, Chapters 1 and 2.



Bristol Turret Hydraulic System

Apart from the above, early Bristol turrets employed similar hydraulic components to Frazer Nash Ltd., *i.e.*, engine driven pump, relief valve, oil filter, rams, swivel joints and unions to connect the external and internal circuits (replaced later by a conventional rotating service joint) and a valve box housing master valve, rotation valve and elevation and depression valve. When the rotation ram was replaced by a motor, however, the valve box was withdrawn, a separate control valve was built into the motor casing and the remaining valves were fitted as separate units.

The Bristol electrical system[1]

The structural appearance of the all electric turret, and the mechanical functions of the components employed, compared very closely with the hydraulic version. Power was supplied by an engine driven generator and fed into storage batteries. The batteries were connected through the appropriate switches, etc., to a motor-generator, mounted on the under side of the turret, a rotating service joint being used, to connect the external and internal turret circuits. The motor-generator consisted of a central motor, driving two separate generators, mounted one on either side. These generators were connected respectively, to a turret rotation motor and an elevation and depression motor.

The gunner was provided with control handles similar to those in a hydraulic turret. A rocking movement of these produced elevation and depression of the guns, whilst rotation about the vertical axis controlled turret rotation. Levers fitted to the hand-grips controlled the power supply to the motor-generator just as the master valve in a hydraulic system, governed the main pressure supply. As the gunner moved his control handles, potentiometers varied the power supply to the generators, so determining the speed and direction of rotation of the turret motors. This system of control, *i.e.*, using a separate generator and potentiometer, to vary the speed and direction of rotation of an electric motor, was known as the ' Ward-Leonard ' system.[2]

Early Bristol turrets

All the turrets produced prior to the year 1939, were upper turrets with the exception of one nose and one tail turret, for use in a heavy bomber aircraft.[3] They were very similar in general design and the B.I. Mark IV is mentioned as typical of the early products.

B.I. Mark IV Turret.—This turret represented the highest state of development reached by the pre-war Bristol Turrets. Earlier types carried one gun only and this was either a Lewis gun, or a Vickers Gas Operated gun, both of which were magazine fed. The B.I. Mark IV, however, was fitted with two ·303 calibre Browning guns which, being belt fed, were a marked improvement. In addition, the arc of rotation of the guns was increased by using two rams. The turret rotation ram was controlled by the gunner's control handles, whilst the separate gun rotation ram was operated by foot pedals.[4]

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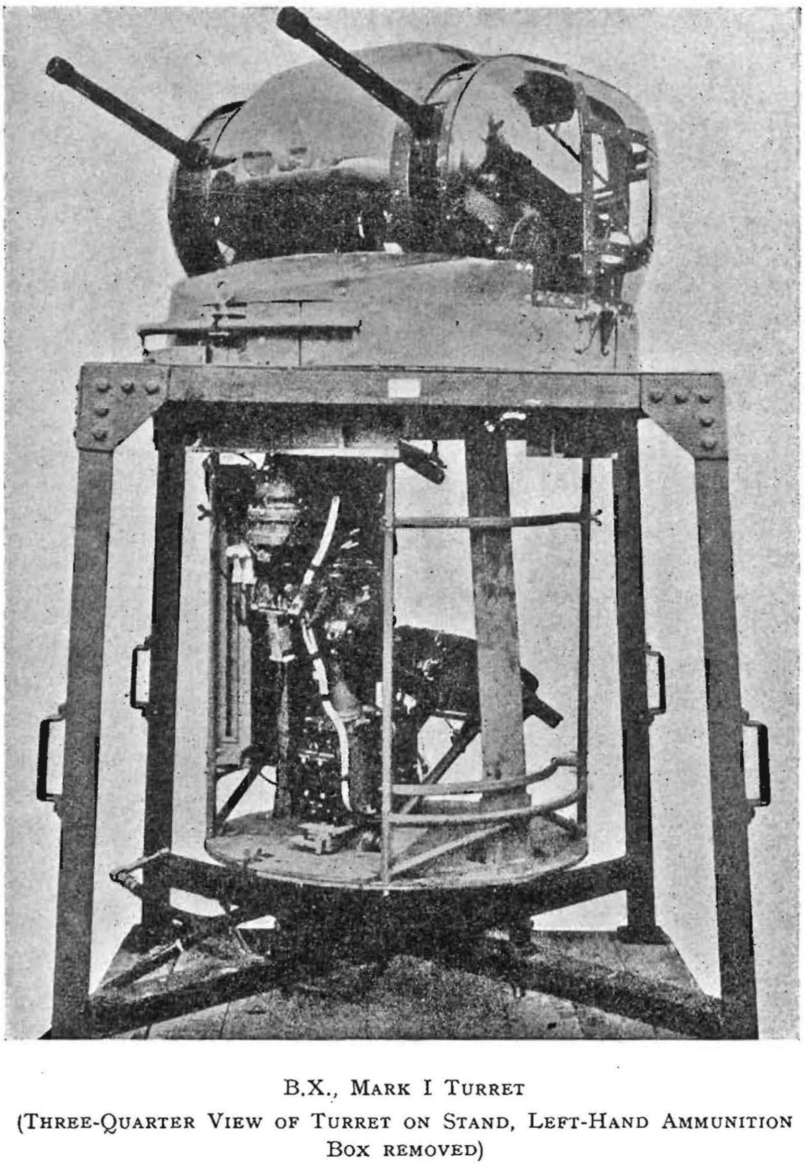
[1] A.P. 2768E, Vol. 1. [2] A.P. 1095B, Vol. 1, Sect. 8, Chapter 1.

[3] A.M. File S. 45405. [4] A.P. 1659B, Vol. 1, Chapter 9.

Development during the period 1939 to 1945

No further improvements were made to Bristol turrets until the end of 1941, when the B.X. Mark I turret was introduced for use in a light bomber aircraft.[1]

B.X., Mark I Turret.—The general design and layout of this turret, were very similar to those of the earlier types. For the first time however, full rotation in azimuth was achieved by using a rotation motor, instead of a ram(s). Two ·303 calibre Browning guns were fitted and other minor alterations



B.X., Mark I Turret
(Three-Quarter View of Turret on Stand, Left-Hand Ammunition Box removed)

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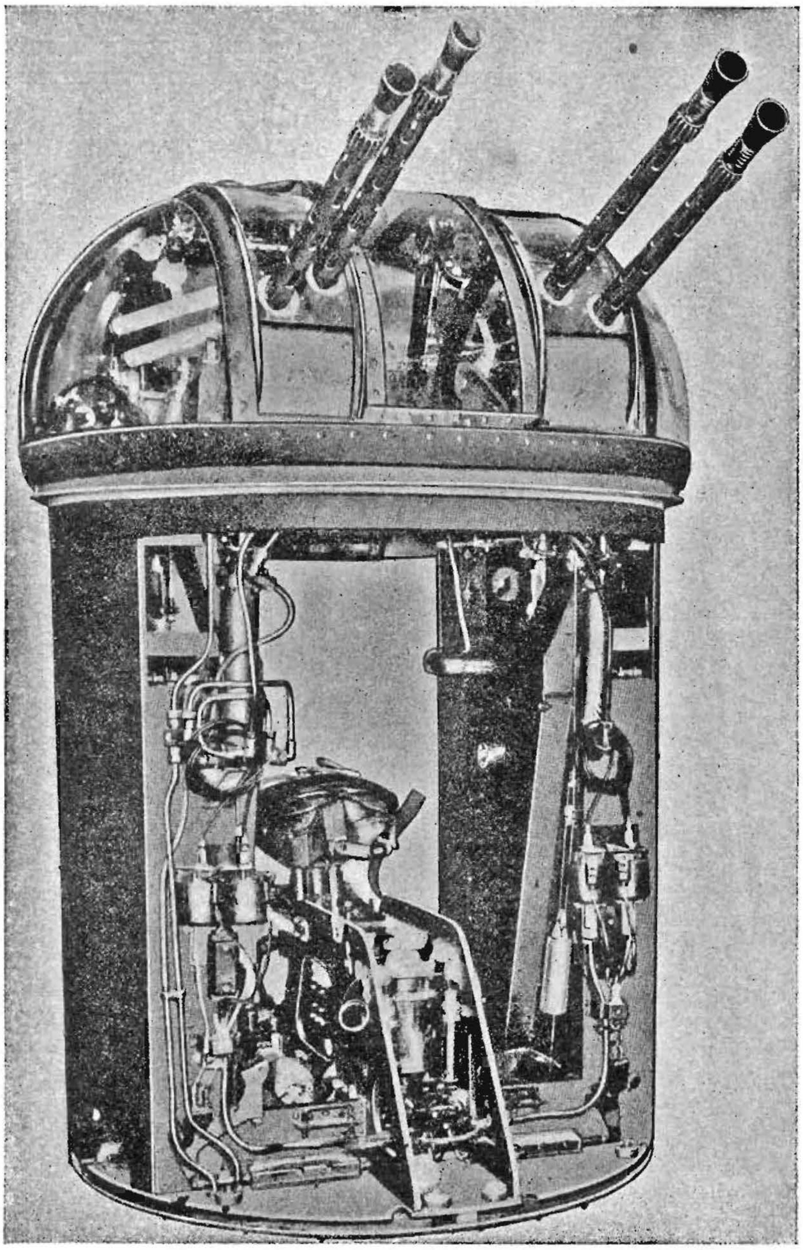
[1] A.M. Files S.50222 and H.S. 68890.

were made such as the use of a conventional rotating service joint, a fixed gunner's seat and an improved cupola. A Gyro-Gunsight was fitted, after the turret had been introduced into service.[1]

The B.X. turrets were followed by the B.12 series, produced as upper turrets for heavy bomber aircraft. None of the aircraft concerned operated to any



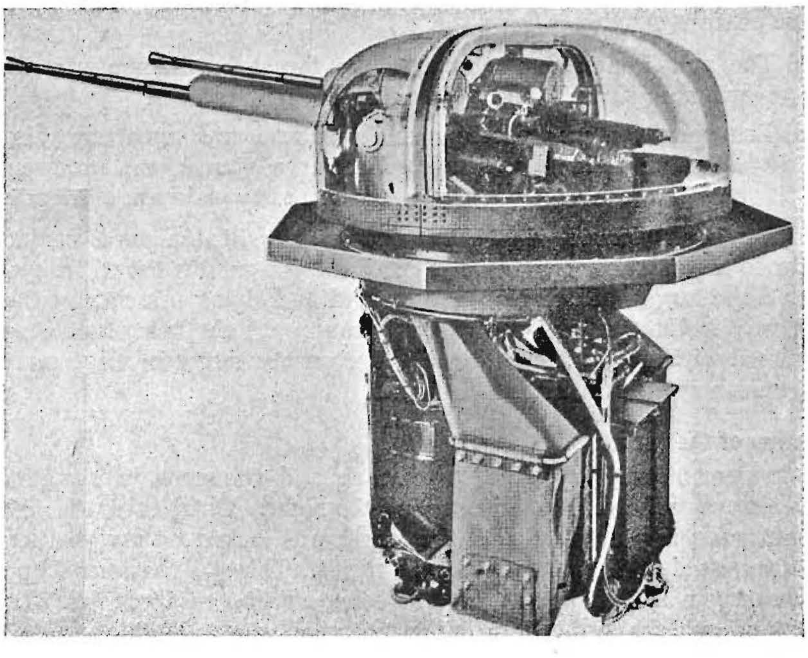
B.12, Mark V Turret
(Front View op Turret with Armour Doors and Floorboards removed)

[1] A.P. 1659B Vol. 1 Chapter 10.

great extent in that role, hence only a limited number of the type were produced. These turrets did however, show a great improvement in general design and are therefore worthy of note. The B.12 Mark V is presented as being typical of the series.[1]

B.12 Mark V Turret.—This turret had an increased internal diameter (approximately ten inches) and all the components were arranged around the inside of the main structure instead of around a central pillar. This gave increased comfort to the gunner. In addition it was the first Bristol turret to carry four ·303 calibre Browning guns and was in production by August 1944.[2] At this stage, development work on hydraulic turrets ceased and the firm concentrated on the production of an all-electric turret, carrying guns of 20-mm. calibre. Work on this project was already in hand in April 1943 and the first turret was delivered in April 1945, just before the end of the war in Europe. This was known as the B.17 Mark I, an upper turret for heavy bomber aircraft.[1]

B.17 Mark I Turret.—The layout of this turret resembled that of the B. 12 series. All components were arranged around the inside of the main structure, apart from the control handles, which were placed centrally in front of the gunner. It was the first turret, of any make, to carry weapons of 20-mm. calibre. It provided reasonable comfort for the gunner, a reasonably clear field of vision, and weapons equal in calibre to any likely to be opposed to it. Furthermore the system was completely electrical and so satisfied the latest Air Staff requirements.[3]



B.17, Mark I Turret

[1] M.A.P. File S.B. 43898 and A.M. File C.S. 21434.
[2] A.P. 2768A *et seq.*
[3] A.P. 2768E.

CHAPTER 17

ROSE TURRET

The Rose turret was designed with three main principles in view: firstly to provide an adequate range of vision: secondly to enable the gunner to bring sight and guns to bear on the target instinctively and quickly; and thirdly to provide heavier armament than ·303 inch calibre guns.

Vision

A disadvantage to other power operated turrets was the restricted vision afforded the gunner. In air warfare it was essential that a gunner had unrestricted facilities for search. Small perspex panels, complicated feed mechanisms, and bulky gun cradles, all tended to distract and limit the air gunner's vision. In the Rose turret, the gunner was afforded excellent search facilities, particularly downwards. It was even possible to see vertically downwards, and with the turret dead astern to see both wing tips of the Lancaster aircraft.

Control

In all other power operated turrets, before a gunner could bring his sight to bear on a target, it was necessary for him to operate handles on a control column, in order to position sight and guns on the point of aim. Such methods had two obvious disadvantages :—

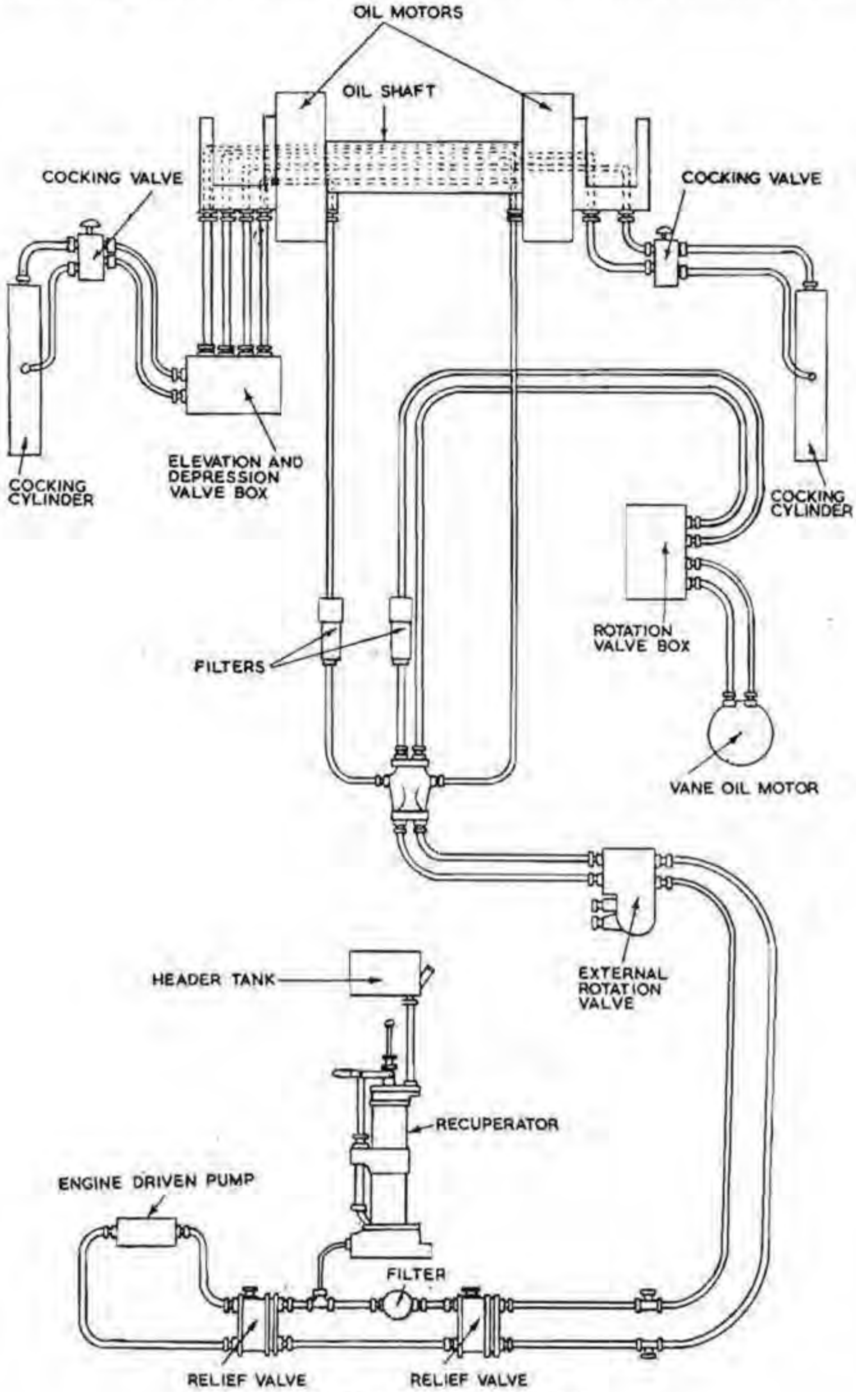
(*a*) The gunner at night often lost the target he momentarily sighted, whilst sight and guns were being brought to bear.

(*b*) The operation was purely mechanical and was unnatural, also considerable training was needed before a gunner was proficient. In addition, constant practice was required to maintain efficiency.

On the ground with a shot gun, and a target in sight, the gun is instinctively brought to the shoulder, a sight taken, and the gun fired without the eye being taken off the target. Similarly, the first and underlying principle of the Rose turret was instinctive sighting and shooting; a sight being taken and the guns aimed without having to take the eye off the target in view, movement of the guns being controlled by the sight.

Operation of the turret

All movement of the turret in azimuth and the guns in elevation and depression was effected by movement of the sight. On release, the sight and guns automatically elevated and the turret was locked in any position by a normaliser fitted at the top centre of the turret. This was the normal 'parked' position of guns and sight, leaving the gunner with an excellent field of search. The guns could be fixed in a horizontal position for loading and clearing stoppages. The gunner's seat was a mushroom sloped rubber pack which could be raised or lowered to suit the gunner's height. A back rest, containing the gunner's parachute was fitted immediately behind the seat. The floor of the turret was fixed, to permit the human sense of direction, and carried a wooden rib fitted to point fore and aft in relation to the aircraft. This rib was fitted so that the gunner could retain his sense of direction in the dark through contact with the feet. This was considered essential when the direction of attack was passed to the air gunner by other than usual means so that he



ROSE TURRET HYDRAULIC SYSTEM

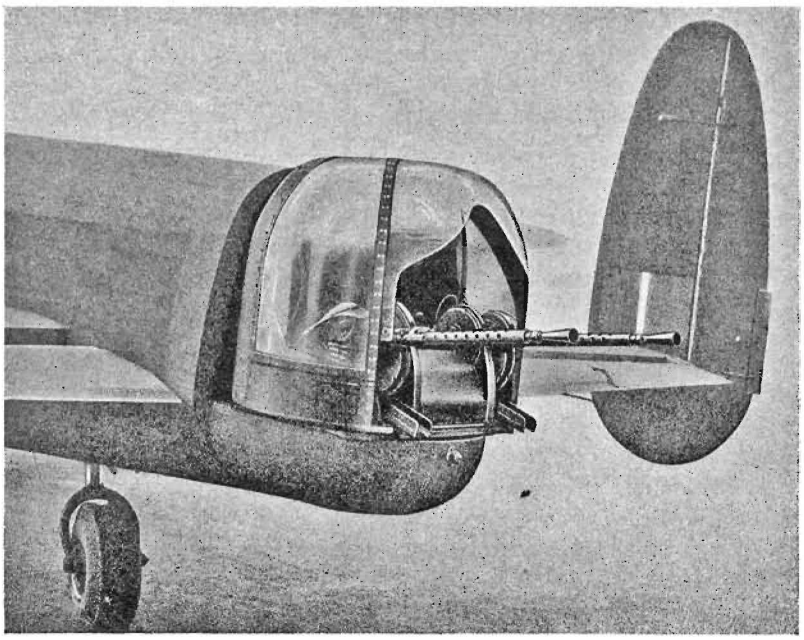
could judge the angle and bring his guns to bear or search instantly, without reference to indicators. The gunner had ample room in the turret, and the centre cut away panel, apart from affording excellent search conditions, could also be used as a means of exit in an emergency.

Hydraulic system

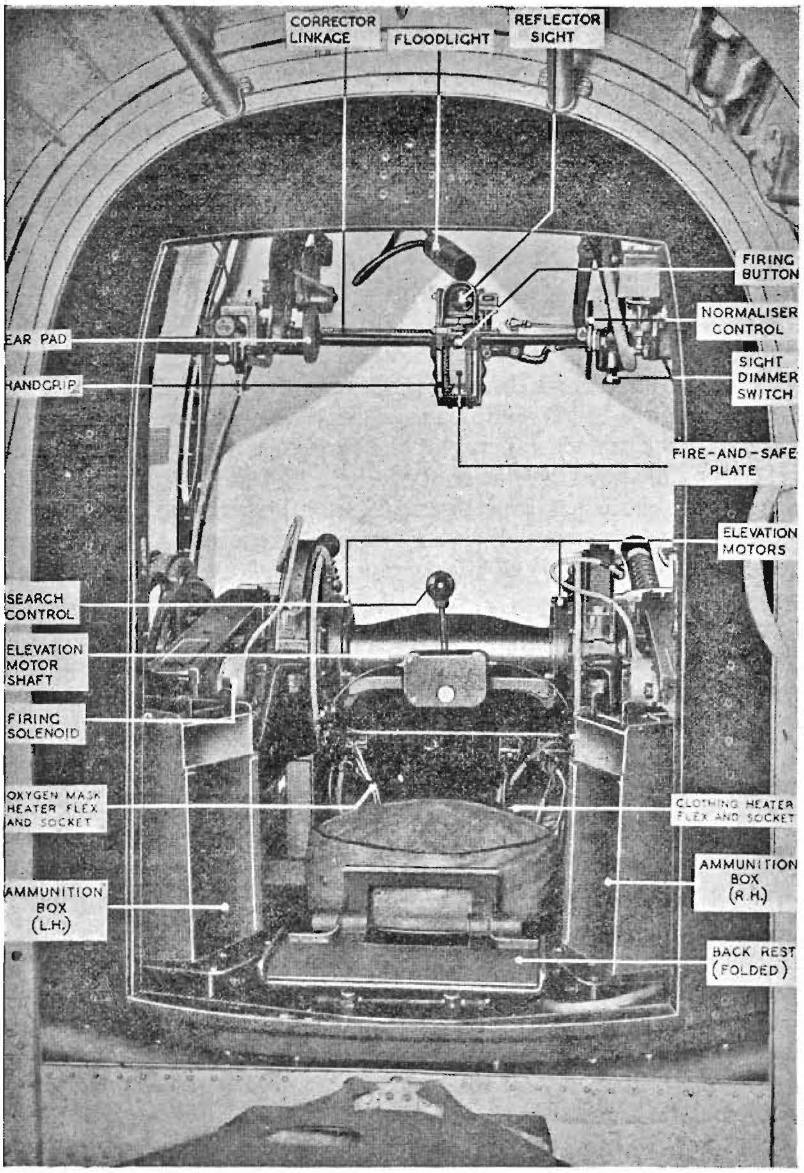
Rotation of the turret was accomplished by the use of the standard Frazer Nash rotation motor and movement of the guns in elevation by oil motors. Incorporated in the hydraulic circuit was a small by-pass oil motor which vibrated a valve and by this means kept the oil moving to prevent freezing. Owing to the absence of rams, any air in the system was expelled during the normal operation of the turret, and after installation it was only necessary for the guns to be fully elevated and depressed to clear the system of air.

Rose Turret No. 2 Mark I

During trials in March 1944, sight vibration during firing was found to be very severe. It was considered that the basic cause of the vibration was either flexure of the turret base plate on fixed ring, or, relative movement between fixed and moving rings. Two turrets were modified in which a damping device was incorporated at the sight arm pivots and in one turret, considerable stiffening was added to the cupola. Although the vibration was reduced considerably, it was still too great to be acceptable to the Service. Photographic records taken on a subsequent trial showed that the turret support was moving with respect to the aircraft. It was known that the tail turret supporting structure of the aircraft was not very rigid and a gusset plate was riveted to either side of the fuselage and anchored to the turret band supporting frame.



Rose Turret No. 2, Mark I, in Lancaster Aircraft



ROSE TURRET NO. 2, MARK I—INTERIOR VIEW

Re-design of cupola

Difficulties in heating the turret, with the large clear vision area, had been foreseen in the early stages of development, and in May 1944, the turrets were being used in Pathfinder squadrons and the gunners complained of the cold. To counteract this excessive draught, the clear vision panel was substantially reduced by closing the opening at the top. This meant that the gunner had to sight through the perspex at all angles above the horizontal.

When it was required to rotate the turret for search purposes, the gunner had to raise his arms to grasp the sight arm ; this proved to be very tiring and detrimental to the blood circulation. In order to facilitate hand rotation, a Bowden cable was fitted, operated by a lever placed centrally in front of the gunner, which enabled the turret to be rotated hydraulically from beam to beam.

The turret with modified cupola and hand rotation mechanism was finally accepted as suitable for Service use and was introduced into the Service in September 1944,[1] for use in the tail of heavy bomber aircraft.

Fitting of gyro gunsight

In the early design stages it was thought that it would be possible to use the gyro gunsight with the turret after the sight arm had been suitably modified, but this sight required a much more rigid mounting than the normal reflector sight. Excessive vibration would cause the moving graticule to disappear and even slight vibration made ranging of the target extremely difficult and liable to error. A trial installation was ready for test in June 1945, but the vibration of the sight was serious. Investigations into the remedial action necessary showed that the necessary modifications would take a long time to incorporate and the requirement for this sight was cancelled in November 1945.

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[1] A.E.C. Submission No. 1826.

CHAPTER 18

REMOTELY CONTROLLED AIRCRAFT ARMAMENT

The ' remote control ' system applied to aircraft armament, was designed to enable the gunner, from the most convenient position, to operate a number of barbettes so situated as to obtain the best possible field of fire. Furthermore, owing to the possibility of amplifying the gunner's manual control, heavy calibre guns could be directed within very fine limits. The system in fact was regarded as the only satisfactory answer to the turret problems of poor vision, lack of heat and the need for heavy calibre guns,[1] and although every effort was made to speed up experiments, the complicated nature of the equipment was such that approximately four years were required for development.

There were several different methods of establishing a link between the gunner and his guns, *e.g.* electrical, mechanical, hydraulic, either separately or in combination. This chapter, however, will be devoted almost entirely to an all-electric system which was produced between 1942 and 1945. Other methods were developed, or partially so, during the same period but were discarded in favour of the electrical system. Technical details of such a complicated mechanism cannot be dealt with in a monograph of this nature but sufficient data will be given to enable the reader to form a reasonable idea of the problem in addition to following the chronological order of development.[2]

Initial planning

Research started in November 1941 when the Air Ministry, in conjunction with the Admiralty Research Laboratory,[3] designed a hydraulic system. This was subsequently discarded as unsatisfactory in the summer of 1942. In the meantime, Boulton Paul Ltd. were producing electro-hydraulic turrets and British Thomson Houston, Ltd., had been working on electrical remote control systems for ground use. In May 1942 therefore, the Air Ministry placed a contract with these firms for the development of an all-electric system to fit one of the standard Boulton Paul turrets, the system to be adaptable to remote control. In addition they were required to develop an all-electric remote control link. After due consideration a conference was held at the Royal Aircraft Establishment (R.A.E.), in August 1942, and the following decisions were reached :—

(*a*) Guns of 20-mm. calibre should be used. A suggestion had already been made that ·5-inch guns should be provided for, but it was considered advisable to use guns of the heaviest possible calibre.

(*b*) The barbettes were to be fully rotatable in the first place but adaptable to limited rotation later.

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[1] M.A.P. File S.B. 55530/2 Parts 1 to 7.

[2] Technical details of remote control systems in general can be obtained from A.M/S.D. 642F. Chapter 1. (Admiralty reference : C.B. 04512F Chapter 1.)

[3] R.A.E. Technical Note Arm. 269 (FC) dated February 1944.

(*c*) Alternating current (A.C.) generated at 250 cycles per second was to be used. The General Electric Company of America were also experimenting with remote control, using A.C. at 400 cycles per second. The higher frequency permitted the use of smaller motors and it would have been desirable to adopt the same frequency. However, as all our aircraft were already using the lower frequency and as the reduction in motor size would be offset by the necessity for larger gear-boxes etc., it was decided not to change the frequency.

(*d*) Boulton Paul Ltd., were to be responsible for all mechanical matters, British Thomson Houston Ltd., for all electrical matters and the R.A.E. for special research and testing.

This plan only provided for the bare necessities but by October 1942, the Air Ministry made known their full requirements, as follows :—

(*a*) The remote control link was to be capable of handling two, and later four, barbettes from a single sighting station.

(*b*) The gunner's sight was to be manœuvrable independently of the barbettes, so as to facilitate search. The barbettes, however, were to be made to 'lock in' automatically when a target was sighted.

(*c*) When the gunner ceased to use his sight, the barbettes were to return automatically to a central position, with the guns pointing dead astern, in order to reduce drag.

(*d*) A 'convergence'[1] computor was to be designed and incorporated by the R.A.E.

(*e*) The system was to include the usual 'cut-out' mechanism to prevent the guns damaging the aircraft structure.

(*f*) The barbettes were to be interchangeable as far as possible, between all likely positions in the aircraft fuselage, *i.e.*, upper, under or side. They were to be fully rotatable.

(*g*) A gun cocking system was to be provided ; initially this would be pneumatic, but later electric.[2]

(*h*) Heating was to be provided ; sufficient to keep the guns at not less than 0 degrees Centigrade under arctic conditions (— 50 degrees Centigrade).

(*i*) The gunner's sighting station was to have the best possible view, include anti-dazzle arrangements and a direct-vision panel for use at night, should this be found necessary. In addition protective armour and bullet-proof glass were to be fitted and the station, as a whole, developed as a separate unit easily adaptable for use in any heavy aircraft.

(*j*) The system was to include an auxiliary sighting station, accessible to any member of the crew in an emergency.

(*k*) Although not required immediately, pressurisation was to be considered.

[1] The reader will readily appreciate that when aiming a sight and guns at a target, both being widely separated in the aircraft, it was necessary to make an angular allowance for the variation in direction between the line of sight and the gun barrel axes.

[2] Remotely controlled cocking was eventually abandoned owing to the risk involved in charging a gun with heavy calibre ammunition which might be fitted with sensitive nose fuzes and contain high explosive or incendiary charges.

(*l*) The designers were asked to bear in mind the probable necessity for fitting radar assisted sighting equipment (A.G.L.T.). Work on blind sighting and firing equipment was well advanced.[1]

Development during 1943

Planning was completed by the end of 1942 including a decision to provide the pilot with an indicator, positioned on his instrument panel, showing the attitude of the guns and so helping him to make the correct combat manœuvres. Furthermore an estimate had been made of the total weight of a system consisting of a sighting station and two barbettes, carrying two 20-mm. guns each. The weight was expected to be approximately 3,000 pounds; equivalent to that of three conventional turrets. The barbettes, with their heavy calibre weapons, were considered to be more effective than the normal armament and as the complete installation would not upset the aircraft centre of gravity, this was regarded as satisfactory.

By March 1943, a wooden 'mock-up' of the sighting station was ready and good progress was being made with the fitting of an 'amplidyne'[2] system to an ordinary Boulton Paul turret. In the same month, difficulty arose in trying to fit the radar 'scanner', for the new blind firing equipment, to the sighting station. It was found that, owing to the bulk and the fact that it had to be fitted to the aircraft stern, it interfered with the gunner's downward view. The only solution was to fit 'blisters' to the sides of the station, to enable the gunner to see round the scanner. The scanner could not be placed underneath the station because it would have produced excessive drag.

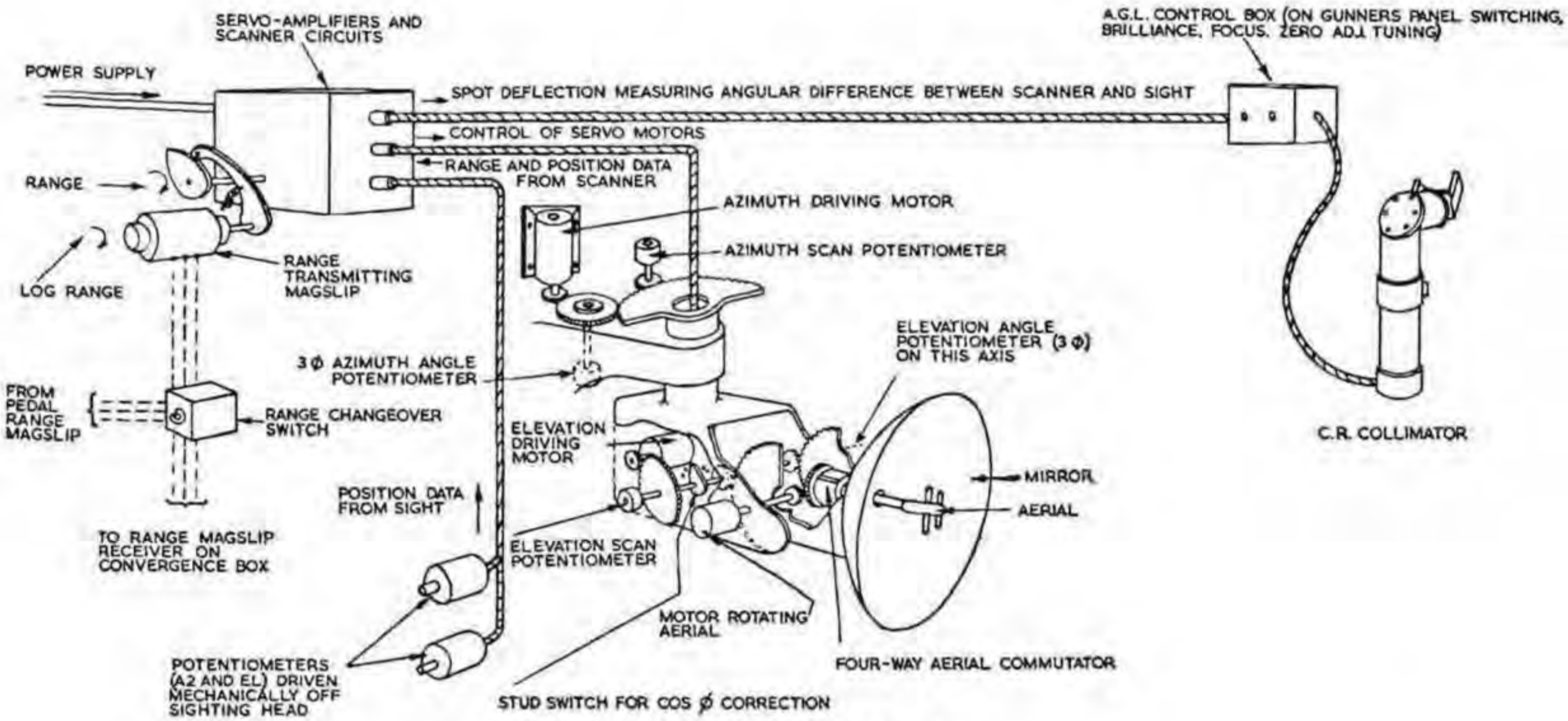
In March also, Vickers Armstrong Ltd. were invited to take part in the development of remote control. They were asked to produce a system having barbettes mounted in the engine nacelles, so providing an almost unobstructed field of fire to the rear. The R.A.E., in the meantime, were experimenting with both electric and hydraulic controls, in an endeavour to find a system giving both good low speed characteristics and the best possible maximum/minimum speed ratios. An amplidyne type of system, known as the 'Ward-Leonard', was being developed but still required refinements, so hydraulics were also being studied as an insurance against possible failure.

During the remainder of 1943 work progressed steadily. In April the R.A.E. confirmed, as a result of research, that alternating current at 250 cycles per second should definitely be employed because the only immediate advantage to be gained from the use of 400 cycles per second, would be standardisation with American research projects. They also suggested that Metropolitan Vickers Ltd., should be invited to start official research as they had found a new vibrator[3]

[1] M.A.P. File S.B. 55530/2 Part 1. *See* A.M/S.D. 642F Chapter 1. (Admiralty reference: C.B. 04512F Chapter 1.)

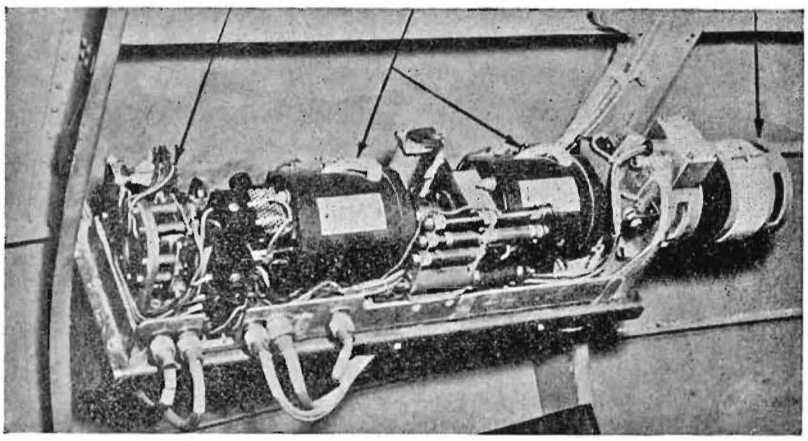
[2] Ordinary electric motors, controlled by normal rheostats, etc., would not provide the low speed torque, or fine control, necessary for operating turrets at a voltage as low as that of the normal aircraft circuit. The amplidyne however, achieved the necessary flexibility by employing a driving motor which was supplied from a special generator, the field of which was separately controlled.

[3] A vibrating solenoid device for controlling the separately excited generator field of the amplidyne circuit. *See* A.M/S.D. 642F Chapter 1. (Admiralty Reference: C.B. 04512F Chapter 1.)



Schematic Diagram of Scanner

control which greatly improved the Ward-Leonard system. In July the Air Ministry stated that all concerned expected the remote control system to be ready for air test in May 1944. The R.A.E. published a report in October, on the gunnery error likely to be caused in flight by flexing of the aircraft structure. They had made a series of air tests to check the extent of the distortion of an aircraft wings and fuselage and found that it was both large and variable, according to the air stability and load conditions. This meant that in some aircraft, large gunnery errors were likely to occur, particularly where the sighting station was mounted in the tail and the barbettes in the engine nacelles. They stated further that, as the errors varied greatly with changing conditions, it would be impossible to introduce any sort of standard correction. Hence they could only suggest that this matter would have to be borne in mind when fitting remote control systems to specific types of aircraft.[1]



WARD-LEONARD UNIT

Development during 1944

Early in January 1944 Boulton Paul Ltd., reported that the upper barbette was ready for assembly and should soon be available for functioning tests, to be followed by firing trials. This was followed by a conference at the R.A.E. to decide the future policy with regard to the separate projects at Vickers Armstrong Ltd., and Metropolitan Vickers Ltd. It will be recalled that Vickers Armstrong had been invited in 1943, to develop engine nacelle barbettes and their own remote control link. Nacelle barbettes were no longer considered advisable as a result of the report from the R.A.E. on aircraft distortion in flight. Furthermore, their link was electro-hydraulic and not particularly efficient. Metropolitan Vickers Ltd., had been asked to develop an all-electric link, using their own vibrator controlled 'metadyne'[2] system ; this was proving less efficient than the amplidyne produced by British Thomson Houston Ltd. After due consideration both projects were cancelled.

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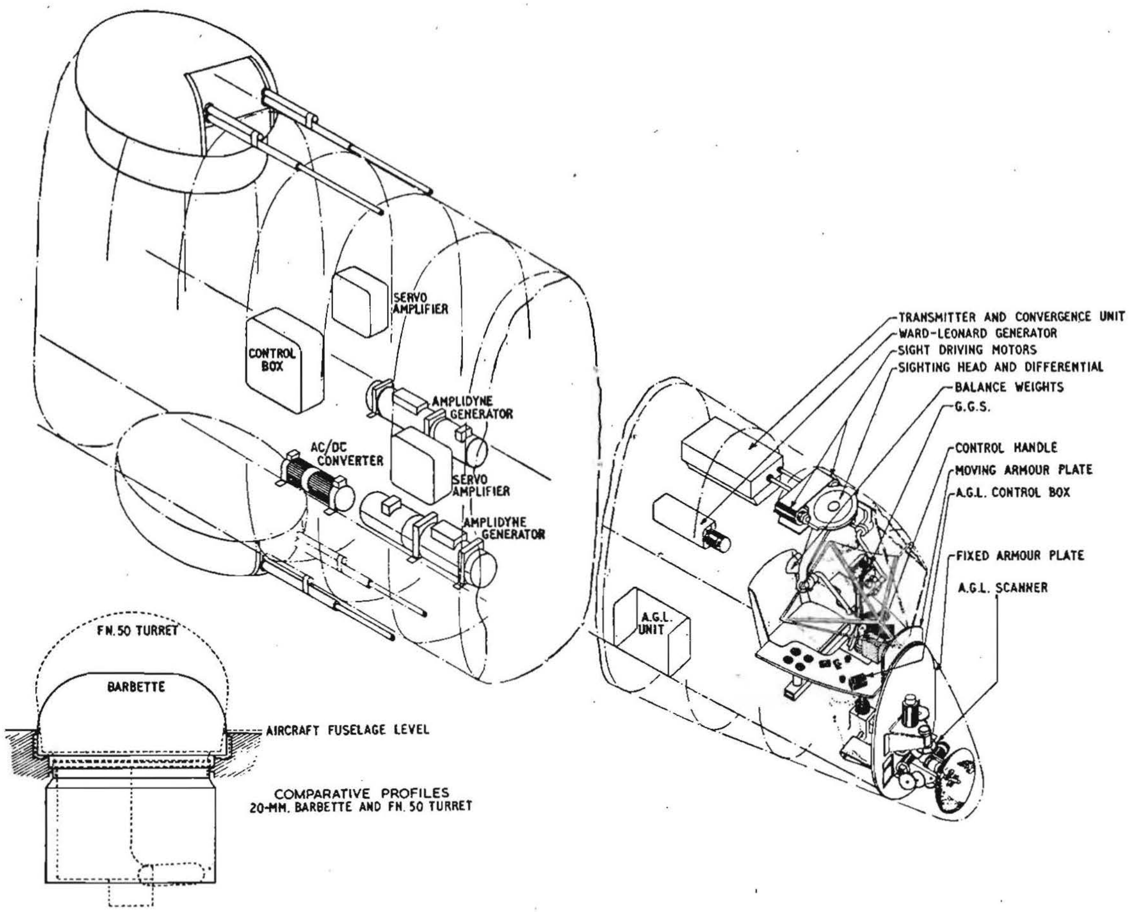
[1] M.A.P. File S.B. 55530/2 Parts 1 and 2.

[2] The metadyne principle is very similar to the amplidyne. The difference lies in the method of controlling the output of the special generator which feeds the driving motor. A.M/S.D. 642F Chapter 1. (*See* Admiralty Reference : C.B. 04512F Chapter 1.)



Remote Control of 20-mm. Barbettes from Tail Sighting Station

Early in June, the upper barbette was installed in an aircraft fuselage, ready for demonstration to the R.A.E. and the firm turned their attention to the problem of fitting radar assisted equipment (now known as ' Village Inn ') to the sighting station. By the end of the month the under barbette was also ready and it was expected that both barbettes would have passed their functioning tests and be ready for firing trials in July. Meanwhile, Metropolitan Vickers Ltd., were still experimenting with remote control but had discarded all-electric designs in favour of electro-hydraulic.[1]

At this stage the Air Ministry considered that the time had arrived to organise the production of standard sighting stations and barbettes, to fit all possible positions in any type of aircraft. To this end the Air Staff were requested to submit detailed requirements and these included suggestions for separate upper and side sighting stations, in addition to the tail station already being developed. They thought that such stations would probably be required to provide full under defence for the very large aircraft which were being considered at that time. Again Boulton Paul Ltd., and British Thomson Houston Ltd., were selected provisionally, to handle the development. This called for careful consideration by all concerned and the preliminary specifications were not available until October 1944.[2] Meanwhile, on the 15th July, the under barbette was given preliminary ground firing tests by the firm in preparation for the full ground firing trials on the Air Ministry test range, at Pendine in South Wales. These tests were entirely satisfactory so both upper and under barbettes were forwarded to Pendine. They proved equally efficient during exhaustive tests which lasted from August to October.

The ground trials were completed at the end of October and a favourable report was rendered on both barbettes. They had been fully tested for :—

(*a*) Accuracy of fire.
(*b*) Smooth functioning.
(*c*) Efficiency at all angles of elevation and depression.
(*d*) Rates of fire under varying conditions.
(*e*) Efficiency of the electrical system.
(*f*) General accuracy after wear.
(*g*) Functioning under the influence of gravity.

The next step was a complete overhaul by the makers, prior to forwarding them to the R.A.E. for air test. This was the first positive step towards the production of a remote control system for operational use, and was followed by the presentation to Boulton Paul Ltd., and British Thomson Houston Ltd., of the official specification for a standard sighting station, barbette and remote control link. The specification was only provisional and the firms were asked to comment.[4]

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[1] M.A.P. File S.B. 55530/2 Parts 3 and 5.

[2] M.A.P File S.B. 61500/2.

[3] M.A.P. File S.B. 55530/2 Parts 5 and 6.

[4] A resumé of the specification is given in Appendix 3 to provide the reader with a reasonable idea of the mechanism and performance of an all-electric remote control system which, had it been available for operational use, would have proved without doubt, a revolutionary improvement to heavy bomber armament.

PART IV

AMMUNITION AND PYROTECHNICS

CHAPTER 19

AMMUNITION

The weapons adopted for Service use at any particular period are, in theory, the best calibre for the conditions prevailing at the time; namely, those which would give the minimum total installation weight necessary to destroy the target. This is not necessarily the minimum calibre capable of destroying the target.

During the First World War, the ·303-inch bullet was reasonably effective against the aircraft then in use. Towards the end of the war, however, a limited amount of armour was being provided to protect the pilot from rifle calibre bullets. In consequence, the Air Ministry decided that the future weapons should be of ·5-inch calibre in order to defeat this armour. Shortly after the war, however, it was decided not to protect British aircraft by armour in accordance with the general trend in which aircraft performance always took priority over armament. Nevertheless, the development of ·5-inch calibre guns was continued, and as the years passed, the fact that this calibre was originally adopted to defeat armour, appears to have been overlooked. Trials in 1928 showed that against contemporary aircraft the larger calibre had no advantage, and with the development of more efficient forms of incendiary ammunition, ·303-inch remained the best calibre for air to air combat until the introduction of armour protection.

Increase of fire power

The destructive effect of both ·303-inch and ·5-inch calibre weapons was due to the impact of solid projectiles known as ' ball,' plus a proportion of incendiary bullets to ignite any petrol or oil leaking out as a result of previous damage by ball. When aircraft increased in size and complexity and it became obvious that increasing quantities of rifle calibre projectiles would be required to ensure their destruction, the use of explosive projectiles was investigated. This resolved itself into two problems; first, the minimum size of shell that would destroy an aircraft with one hit, and second, the minimum calibre for which a satisfactory explosive shell could be made. Some work was done on the first problem in this country, but the second problem was investigated on the Continent.

Up to 1939, the minimum calibre that would be lethal with one hit was considered to be 40-mm. and the Vickers ' S ' gun was originally designed for this purpose. It was intended to be used in a power operated turret in conjunction with a range finder and predictor gear. Before this installation had been fully developed, however, it was apparent that something much larger than 40-mm. would be required to destroy modern aircraft with one hit, and all work on large calibre guns for air to air fighting ceased early in 1940. Meanwhile, most of the Continental arms manufacturers had come to the conclusion that 20-mm. was the minimum calibre in which a satisfactory high explosive projectile could be manufactured, and 20-mm. guns were adopted by most European powers for both air to ground and air to air fighting.

After a lull of twenty years, the question of armour protection for aircraft was reviewed during 1939. Trials to ascertain the damaging effects of various calibre ammunition were carried out and it was soon apparent that a large measure of protection could be provided against ·303-inch in contemporary aircraft without excessive increase in weight. This led to the provision of armour protection in British aircraft. It was realised that the enemy would also sooner or later, provide armour protection, in which case the effectiveness of ·303-inch ammunition would be greatly reduced. This was met by the adoption of the 20-mm. Hispano gun as standard armament for all future fighter aircraft. The design and development of the ammunition for the Hispano gun is dealt with later in the chapter, as it was in this field that most progress was made.[1]

The bomber problem was more difficult. The Hispano gun was too large to install in any gun turret in production or in the prototype stage, and this led to urgent action to obtain ·5-inch calibre guns. After extensive trials of various calibres of ammunition against armour plate, it was decided that it would be possible to provide armour protection against ·5-inch ammunition, but the extra weight to provide protection against 20-mm. ammunition would be prohibitive on contemporary aircraft.

For the attack of unarmoured ground targets, the 20-mm. showed the same superiority over other calibres as it did in air to air combat. For attacking armoured targets from the air, however, the position was different, and in this case the best calibre was the minimum that would penetrate the armour of the target. Three types of gun were developed for this purpose; the Vickers' 40-mm. 'S' gun and the 47-mm. and 6-pounder.

20-mm. Hispano ammunition

When the 20-mm. Hispano gun was adopted in 1936, the tactical use of weapons for this calibre had not received much consideration and there was no clear idea as to what types of ammunition would be required. The Hispano Company had designed three types:—

(*a*) Ball,

(*b*) Incendiary,

(*c*) High Explosive,

and all early trials were carried out with ball ammunition of French manufacture.

In July 1937, a meeting was arranged between the Director of Armament Development (D.Arm.D.) and the War Office departments concerned, to determine R.A.F. requirements for 20-mm. ammunition, and the following conclusions were reached[2]:—

(*a*) Practice ammunition and pointed shot would probably be formed from the same shell body.

(*b*) Armour piercing shell need not be produced if ordinary pointed shot proved to have good penetrating power.

(*c*) A 'base fuzed' shell was to be developed with a delay of six inches and with an impact velocity of 2,310 feet per second.

(*d*) Incendiary and explosive shell would use the same shell body.

[1] Appendix 6 gives a list of ammunition used during the period under review.

[2] A.M. File S. 51401/1.

(*e*) A self-destroying fuze was not required.

(*f*) Tracer ammunition was not required.

(*g*) A British design of shell and British type of propellent suitable for 20-mm. ammunition should be developed.

(*h*) All types of projectile to be developed should have the same ballistic properties and should range together.

These conclusions were based on air to air fighting from fixed gun fighters, and were considerably modified as the result of operational experience.

It was decided that the Superintendent of Design (S. of D.) would produce the ammunition, based on the original Hispano design. Close co-operation was also to be maintained with the French Air Ministry who were themselves making modification to the ammunition design. There was one important point in which the Hispano design was considered unsatisfactory. To ensure correct functioning of the gun, all French ammunition was oiled. This was contrary to British practice and S. of D. aimed at producing a cartridge case that would function without oiling. In this he was successful and oiled ammunition was never used in the British made Hispano guns. First priority was given to the development and manufacture of Ball and High Explosive ammunition.

Ball ammunition

This was identical to the original French design, having a flat nose and the same external shape as the H.E. ammunition. Penetration trials carried out in 1939 showed that the Ball projectile would penetrate the armour likely to be carried on any contemporary aircraft, and it was confirmed that an Armour Piercing projectile would not be required.[1] The manufacture of the Ball projectile was a straightforward job and gave very little trouble.

In the early production, some difficulties were experienced due to the projectile not being properly secured in the cartridge case, but this was easily overcome by providing a deeper cannelure in the projectile. Until the introduction of Semi-Armour Piercing/Incendiary (S.A.P./I) ammunition in 1942, Ball ammunition was used on operations, and was equal to the H.E. as regards structural damage to the aircraft. From the end of 1942, it was only used for proof and experimental firing.

High explosive ammunition

The decision to develop and produce H.E. ammunition in this country was made in July 1938 and followed the original French design very closely. It gave considerable trouble in manufacture, and there proved to be a wide variation in performance between the experimental batch of ammunition and that produced under production conditions. At a meeting in March 1939, it was decided that the cartridge cases and caps were to be manufactured by I.C.I., and later also by the Royal Ordnance factories. The projectiles, however, were to be made and filled by the British Manufacturing and Research Company (B.M.A.R. Co.), the subsidiary of the Hispano Co. in Britain.

In manufacturing ammunition, the B.M.A.R. Co. proved to be unsatisfactory. There were considerable delays in commencing deliveries, which did not start

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[1] A.M. File S. 51401.

until June 1940. During the period July to September 1940, the B.M.A.R. Co. had produced approximately 7 'Lots' of H.E. ammunition, amounting to 69,000 rounds. Of this, however, only one 'Lot' was safe for issue to the Service; the rest being condemned by the inspection department on account of the excessive number of prematures experienced during proof. An investigation carried out at the B.M.A.R. Co. factory showed that the filling procedure laid down by the Chief Superintendent of Research and Development (C.S.R.D.) was not being followed, and that the operatives and supervising staff engaged on filling the shells were completely ignorant of this class of work.

The filling procedure was reorganised by a C.S.R.D. representative and a considerable improvement resulted, and by the end of November 1940, a regular supply of H.E. ammunition was reaching the Service. One of the main reasons for adopting the 20-mm. Hispano gun was the destructive effect anticipated from the use of H.E. shells. In practice, the effect of H.E. shells against contemporary aircraft was disappointing; the damage to the structure being no greater than that caused by ball ammunition, and the main value of H.E. was its incendiary effect. Once a satisfactory incendiary had been developed and put into production, the manufacture of H.E. was discontinued, and it had practically ceased to be used in operations by the end of 1942.

High explosive/incendiary ammunition

During the development of a suitable incendiary shell for the 20-mm. Hispano gun, the effect of adding an incendiary pellet to the H.E. shell was tried. The performance of this shell, during tests in May 1939, was impressive, giving better results against petrol tanks than either H.E. or Incendiary. In consequence it was decided to develop H.E./Incendiary ammunition as an alternative to plain Incendiary.[1]

Four types of H.E./I. shell were made up by C.S.R.D. having high explosive and incendiary fillings in various proportions. In December 1939, trials were carried out with the shells, together with a H.E./I. shell of Hispano Suiza design; the results showing that the Hispano shell was more effective against self-sealing petrol tanks.[2] This shell used phosphorous for its incendiary component, however, which was not favoured by C.S.R.D. owing to its poor storage properties and difficulty in handling.

Further trials, with various types of incendiary composition, were carried out during March 1940, and in August, the Director of Armament Development (D.Arm.D.) requested the Ordnance Board to arrange for the development of an H.E./I. shell having equal amounts of high explosive and incendiary composition. Subject to satisfactory trials it was hoped to change over the production of H.E. shells at the B.M.A.R. Co. factory to the new H.E./I. filling. The filling of the experimental H.E./I. shells had been carried out at Ordnance factories under C.S.R.D. supervision, and to prevent a repetition of the trouble experienced with the early H.E. shell, an experienced technician was loaned to the B.M.A.R. Co. to supervise the filling of the H.E./I. shell.

The first small batch were filled towards the end of September 1940, and the ammunition was in full production early in 1941. By the middle of the

[1] A.M. File S. 51422. [2] A.M. File S. 51415.

year a number of prematures were occurring during proof firing of the ammunition, and after some investigation, the trouble was traced to the steel used for making the shell bodies. To facilitate manufacture and free cutting, a steel known as 'Ledloy' was being used.[1] This steel contained a proportion of lead and was found to contain a number of faults, the results being that the base of the shell was often porous, and on firing, the burning propellent ignited the incendiary composition.

It was found that the United States Ordance Department had experienced similar trouble when using lead-bearing steels for shell bodies. After some experimenting the U.S. Ordnance had found that the trouble could be completely eliminated by electrically welding a base plate of non-porous steel to the base of the shell. Some special machines for this welding were obtained from the U.S.A. early in 1942, and no further trouble was experienced.

As originally issued to the R.A.F., the H.E./I. shell was filled with C.E.[2] and S.R. 379, as the high explosive and incendiary compositions. In November 1940, the Ordnance Board had suggested 'Pentolite' might be substituted for the H.E. filling. Trials with various types of 'Pentolite' fillings were carried out but it was never adopted for Air Force use.[3]

In July 1942, the Ordnance Board considered that it would be advisable to test the effect of using aluminium as an incendiary medium, by adding it to the filling of the H.E. shell. Various trials took place with a variety of fillings, such as C.E./aluminium and T.N.T./aluminium, but they showed no advantage over the standard H.E./I. Trials continued until 1944, when it was finally decided to abandon the idea of using aluminium as an incendiary medium.

The standard H.E./I. shell was one of the most satisfactory developed for the Hispano gun ; it completely replaced the H.E. shell and remained in operational use until the end of the war.

Fuzes

The original fuze used on the French design of shell was a percussion base fuze, striker operated, with a centrifugal safety device. It was re-designed by the Superintendent of Design (S. of D.) early in 1939, for production in Britain, but followed the original design very closely.[4] The S. of D. design, known as the Percussion Fuze No. 252, was expensive and difficult to make and was only used on the early production of H.E. ammunition. One of the defects of the No. 252 fuze was that it was so sensitive that the shell would explode on the surface of the aeroplane, doing far less damage than if it had penetrated into the structure before exploding.

During trials carried out at the French Air Ministry in 1939, it was found that the fuze would function if the complete striker mechanism was omitted, and was considerably less sensitive than the original fuze. From this was developed the British design of fuze which was known as the No. 253 Mark I. It was similar to the earlier design and the same magazine containing the detonater, booster cap and C.E. pellet were used. The difference was in the fuze body which had an empty space in place of the striker mechanism, and a thicker end

[1] A.M. File S. 51415.
[2] Composition of Explosives.
[3] A.M. File S. 51473.
[4] A.M. File S. 51422.

cap. This fuze was very successful and was used on the later batches of H.E. ammunition and on all H.E./I. ammunition. It gave sufficient delay to enable the shell to penetrate some distance into the aeroplane structure before detonating.

The magazine of the No. 253 fuze was later completely re-designed, the booster cap and C.E. pellet being replaced by a six grain lead azide/C.E. detonator, and was introduced into the Service in July 1943 as the No. 254 fuze. The 'Base' fuze suggested in 1937 was never developed.

Semi-armour piercing/incendiary (S.A.P./I.)

By the end of 1940, it was apparent that the Germans were tending more and more to armour their aircraft. In particular, they were providing armour protection for the self-sealing petrol tanks. Although the 20-mm. ball ammunition then in use could penetrate the armour without difficulty, it had no incendiary effect, whereas the H.E. ammunition, which had a considerable incendiary effect, would detonate on the surface of the armour without penetrating to the tank. In October 1940, S. of D. was asked to consider the design of a projectile that would both penetrate the armour and have some incendiary effect after penetration.[1]

During 1941, a design of projectile was evolved, which consisted of the standard H.E. body filled with incendiary composition and having an armour piercing tip in place of the fuze. Trials with this ammunition were carried out at Orfordness on 13 March 1942, and in general it was found that petrol in tins was ignited when placed 2 feet behind 18-mm. armour plate. The A.P. tip passed through the plate followed by the incendiary composition in flame, whilst the shell body broke upon the plate. Firing against an aircraft wing was also carried out, and as a result the following conclusions were reached:—

(*a*) About 50 per cent. of projectiles started to flame before hitting the armour, showing that the cumulative effect of passing through a labyrinth of light structure had a chance of starting the flame.

(*b*) The flame continued as long as the projectile was passing through the aircraft, whereas the H.E./I. detonated on a solid object and had only a local incendiary effect.

(*c*) The damaging effect of the projectile alone was not inferior to ball and might prove to be superior.

(*d*) The plate penetration was better than ball but less than straight A.P. It was however adequate for air to air combat, as no armour over 12 mm. was used by the enemy at that time.

Further trials were carried out at Pendine in June 1942, to test gun functioning and safety in stoppages, and to assess the penetration effects. After the successful conclusion of these trials this ammunition was introduced into the Service as Semi-Armour Piercing/Incendiary Mark IZ.

Tracer

Although it had originally been decided that tracer ammunition for the 20-mm. Hispano gun would not be required, the adoption of the system of sighting evolved by Professor Melville Jones, led to a reversal of this decision.

[1] M.A.P. File S.B. 8516.

Accordingly in October 1939, the Ordnance Board were asked to consider the design of tracer for the 20-mm. Hispano gun, similar to that being developed for the ·303-inch calibre.

Various trials were carried out early in 1940, using the same tracer composition as used for the ·303-inch tracer. By that time, however, there was no prospect of 20-mm. turrets being in use for some years at least, and the need for 20-mm. tracer was therefore less urgent.[1] Moreover, it was not economical to develop similar composition in ball 20-mm. and ·303-inch calibre and in May 1940, it was decided that tracer compositions for the Melville Jones method of sighting would be developed for ·303-inch calibre only.

The Director of Armament Development (D. Arm. D.) informed the Ordnance Board in July 1940, that the R.A.F. requirements for 20-mm. tracer were as follows :—

Type 'A' .. A day tracer for ground to air use as a temporary measure, any length of trace being acceptable.

Type 'B' .. A night tracer for air to air use. Minimum length of trace 400 yards ; maximum 800 yards.

Type 'C' .. A day tracer for air to air use, having 0 to 600 yards plus or minus 50 yards, or preferably dark ignition up to 200 yards and bright trace to 600 yards.

Type 'D' .. An A.P. tracer for air to ground use ; minimum length of trace 600 yards.

All were stated to be on high priority, but in actual fact priority was given to Type 'A' as being the easiest to produce quickly, and trials of this ammunition took place at Orfordness during August 1940.

This ammunition was introduced into the Service at the end of 1940, as the 20-mm. Hispano Tracer Shot G. Mark IZ, and consisted of the standard ball projectile with a pellet of tracer composition in the base. It fulfilled the immediate need for a tracer ammunition, but with the recommencement of development of 20-mm. turrets in 1942, the provision of more satisfactory types of tracer became more urgent. It was now decided, however, to combine the requirements for tracer and A.P. in one projectile.

During the latter part of 1940 and early 1941, the detection and illumination of enemy aircraft at night was a major problem and it had been suggested that this could be accomplished by the use of special flare shells. In consequence, the development of a flare shell, or searchlight tracer, was undertaken by the Chief Superintendent of Research and Development (C.S.R.D.). Various trials were carried out during 1941, but were not very successful, and the project was dropped at the end of the year.[2]

Armour piercing

As ball ammunition gave ample penetration for air to air combat, little attention was paid to the development of A.P. shot up to 1940. As a result of the campaigns of the spring and early summer of 1940, it was decided to develop an A.P. shot for the 20-mm. Hispano for the attack of armoured fighting

[1] A.M. File S.51482. [2] M.A.P. File S.B. 8511.

vehicles (A.F.V.) from the air. Trials with various types of A.P. projectile were carried out during the first half of 1941, one of the main difficulties being to produce a shot which would function correctly in the existing 20-mm. gun.

If a solid shot of normal A.P. design, the same length as the standard ammunition was used, it would be so heavy that it would give rise to recoil loads higher than the mounting units or aircraft structure were designed to take. If the length of the ammunition were reduced, it could not be used in the standard belt feed mechanism. In addition to this, the sharp point of A.P. ammunition badly scoured the ramp face of the belt feed mechanism. After some experiment, a projectile with a moulded plastic cap over the nose was evolved. This had the same length and shape as the other 20-mm. ammunition and its weight was not great enough to give heavy recoil loads.

This ammunition was introduced into the Service as armour piercing ammunition Mark IIZ. A small amount of Mark I ammunition had been previously issued for Service trials, but had not been approved for general use owing to its tendency to break up in the bore of the gun. Early in 1942, a consignment of A.P. Mark IIZ was forwarded to the Middle East and trials were carried out against captured German Mark III and Mark V tanks.[1] The results were disappointing, out of 190 rounds fired, 19 hits were obtained, but none did more than score the armour plate for a depth of one quarter of an inch. With the introduction of the 40-mm. 'S' gun at this period, the use of the 20-mm. Hispano for the attack of A.F.V.s became of less importance. The ammunition was retained in service for the time being and was used on a limited scale for air to ground attacks.

After the failure of A.P. Mark IIZ against A.F.V.s an attempt was made to develop a high velocity 'Littlejohn' projectile for the 20-mm. Hispano gun. This project had to be abandoned owing to the difficulty of obtaining satisfactory gun functioning with this ammunition. Another type of ammunition known as the 'composite rigid' was then tried. This consisted of an aluminium projectile with a tungsten carbide core of 11½ millimetres in diameter. On hitting armour plate the aluminium broke up and the tungsten carbide core continued through the armour. Penetration up to 43 millimetres of armour was obtained with these projectiles as against 24 millimetres with the standard A.P. By the time the development of this ammunition was completed, however, the enemy were equipping their Mark III and Mark IV tanks with skirting plates which completely defeated the 'composite rigid' projectile. A limited amount of this ammunition was issued to the Service for trials but it never went into full production.

In 1943, a requirement was formulated by the Air Staff for an armour piercing/tracer ammunition. Various trials were carried out with tracer pellets in the base of the A.P. Mark IIZ projectile. This ammunition had been designed to give maximum penetration against A.F.V.s, and by that time it was apparent that the future use of A.P. would be for air to air combat and that maximum penetration was not so important as good ballistic shape. It was decided therefore, to combine the requirement for A.P. and tracer ammunition in one type of

[1] A.M. File S. 51450.

projectile of improved ballistic shape. Trials of this ammunition took place during 1943, and the following types of ammunition were introduced into the Service during the following year :—

(*a*) Armour Piercing/Tracer Mark IZ (Day).

(*b*) Armour Piercing/Tracer Mark IIZ (Night).

(*c*) Armour Piercing Mark IVZ.

The projectile was of armour piercing steel and had an internal cavity open at the base, and was common to all three types of projectile.[1]

The cavity of the Mark IZ tracer was partly filled with Bakelite, followed by a trace composition which lit up at 50 yards and lasted for 1,000 yards at 15,000 feet. The Mark IIZ contained a night tracer composition which lit up at 50 yards and lasted for 600 yards at 15,000 feet. The Mark IVZ had the cavity filled with Bakelite only. The A.P./Tracer was intended for use in turrets only, while the Mark IVZ was intended for general use as a replacement for the Mark IIZ.

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[1] A.M. File S. 51438.

CHAPTER 20

ROCKET PROJECTILES

The use of rockets for air war purposes can be said to have originated during the First World War when Le Prieur rockets were fired from aircraft, mainly against kite balloons.

The modern rocket was developed by the Research Department of the War Office during the years immediately preceding 1939 and was intended for the attack of aircraft from the ground or as an alternative to the anti-aircraft gun. The War Office formed a Projectile Development Establishment to develop rockets, and a 3-inch diameter anti-aircraft rocket for ground to air use was put into production early in the war.

During the Battle of Britain, in July 1940, the Air Staff formulated a requirement for a rocket that could be fired from fighter aircraft to break up formations of enemy bombers. A scheme to fire the standard 3-inch anti-aircraft rocket from the gun bay of a Beaufighter was proposed, but the success of the existing fighters during this period, made the application of rockets unnecessary and the investigation was dropped.

Various methods of attacking armoured fighting vehicles (A.F.V.) from the air were investigated by the Air Staff during 1941.[1] Trials of the Vickers 40-mm. 'S' gun were arranged and the Director of Projectile Development (D.P.D.) in the Ministry of Supply was consulted as to the possibility of using rocket projectiles for this purpose. On the advice of D.P.D. preliminary trials of armour penetration and aiming dispersion were made with the standard 3-inch rockets fitted with solid armour piercing heads weighing 25 lb. These experiments were so successful that it was decided to proceed with more comprehensive trials.

As the rocket was originally an Army weapon, the design and development of the R.A.F. rockets was carried out jointly by the Ministry of Aircraft Production and Ministry of Supply. In general the Royal Aircraft Establishment (R.A.E.) was responsible for the design of the launching apparatus and the installation of the rocket in aircraft. The Projectile Development Establishment was responsible for the design and development of the rocket motors and ground projection. The Armament Design Department designed the rocket heads and the Armament Research Department developed the rocket propellents. Air trials and performance tests, together with a certain amount of development work, were carried out at the Aircraft and Armament Experimental Establishment at Boscombe Down.

It was decided originally to develop two types of rocket :—

(*a*) The 3-inch rocket with a solid armour piercing head.

(*b*) The 2-inch rocket with a hollow charge head.

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[1] A.M. File C.S. 12512/1.

Some difficulty was experienced in developing a head for the 2-inch rocket which would give the penetration required, and work on this size ceased in the early stages ; development being concentrated on the larger type. These rockets were known in the Army as 'U.P.s' (Unrotated Projectiles) ; in the R.A.F. the name was changed to 'R.P.s' (Rocket Projectiles).

The motor charge

One of the first difficulties with the original Army rocket was the fact that the motor propellent was tubular cordite, with an upper firing limit of 86° F. Above this temperature, bursting of the motor tube occurred due to high peak pressure. This upper temperature limit was considered too low for general air use, and the development of a modified propellent was undertaken by the Research Department of the Ministry of Supply. The propellent developed was of cruciform section and had an upper temperature limit for safe firing of 135° F., which was regarded as adequate for all Service conditions. It also contained a small percentage of cryolite which made the gas jet non-luminous, and thus eliminated the blinding effect on the pilot in night firing. This modified propellent was used in operations throughout the war, first in the Mark II motor, and later in the Mark III motor.

The rockets were fired electrically by the pilot, a lead or pigtail from the rear of the motor being plugged into a socket on the aircraft adjacent to the mounting. In early types of rocket, the pigtail was left swinging under the mainplane and there was a danger of the leads fouling the ailerons. The pigtail of the Mark III motor incorporated a weak link, which allowed the leads to be blown clear of the aircraft when the rocket ignited.

No further modifications were made to motors used in operations. The Marks II and III motors had an inferior performance to the original army type, due to the fact that with the cruciform shape only 11½ pounds of cordite could be accommodated in the tube as against 12½ for the original tubular charge. This meant a reduced velocity, longer time of flight to any given range and increased curvature of trajectory.

The rocket head

Two types of head were designed for use with the 3-inch motor ; a 25 lb. Armour Piercing (A.P.) solid steel shot of 3·44 inches diameter and a 60 lb. High Explosive/Semi-Armour Piercing (H.E./S.A.F.) shell of 6 inches diameter. Originally the A.P. shot was intended for the attack of A.F.V.s, and the 60 lb. head for the attack of merchant ships and submarines.[1] Operational experience showed, however, that the H.E./S.A.P. head was only effective against shipping in the event of a dry hit. If the rocket hit the water before reaching the ship, the head detonated or broke away from the motor. With the A.P. head, however, the shot remained intact on hitting the water and had a long, upward curving trajectory which was ideal for offsetting range aiming errors.

Trials carried out at Pendine in November 1942, using a 25 lb. mild steel (S.A.P.) head against a target representing the hull of a submarine, showed that the S.A.P. shot was capable of inflicting lethal damage with one hit on a pressure

[1] A.M. File C.S. 12512/1.

hull.[1] The results also indicated that about 30 per cent. hits could be obtained on the pressure hull of a U-boat of the 517 ton class. In consequence it was decided to use the 25 lb. S.A.P. head for anti-ship operations in place of the 60 lb. head as originally intended.

Meanwhile early operational experience against A.F.V.s showed that a direct hit on a tank by a 60 lb. H.R. head was lethal and that a near miss damaged the tracks sufficiently to immobilise the tank. Moreover the H.E. head was more effective against general land targets, such as gun positions, concrete emplacements, buildings and personnel. In consequence it was decided to use the 60 lb. H.E. head against A.F.V.s and other land targets, thus completely reversing the use as originally intended for the two types of head.

When used against comparatively small targets such as tanks and lorries, considerable difficulty was experienced in aiming rockets owing to the large allowance necessary for drift. Unlike a bullet, the rocket tends to follow the aircraft line of flight rather than the line of sight, owing to its good weathercock stability. The aiming was improved by special training of pilots.

The 25 lb. A.P. shot and the 60 lb. H.E./S.A.P. head were the standard weapons used on operations throughout the war. Other types of head, however, were used for special purposes. The 25 lb. S.A.P. head was similar to the 25 lb. A.P. except that it was made of mild steel ; originally used on operations, it was later used for practice firing only. Owing to the shortage of steel, concrete practice shots were designed to represent both the 25 lb. and 60 lb. heads. A flare head, containing a parachute and flare, and a smoke container head were also designed, and put into production for Naval use towards the end of the war.

Fuze for the H.E. head

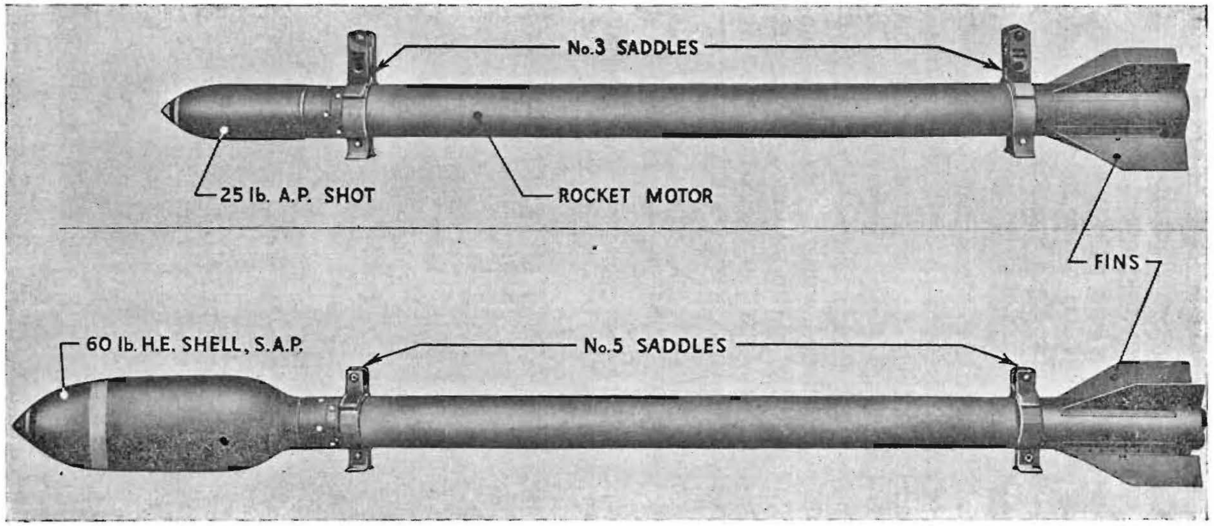
Some trouble was experienced in obtaining a satisfactory fuze for the 60 lb. H.E. head, the main difficulty being to devise a safe method of arming the fuze. The first type used was armed by the gas pressure generated by the burning cordite, but this was not satisfactory and after one had exploded on the aircraft during air firing trials, this type of fuze was discontinued.

The fuze finally adopted was a percussion base fuze known as the No. 865 Mark I. It was armed by a thermal initiator which was operated by the heat generated by the burning propellent. Another fuze, the No. 878 Mark I was also used, being identical with the No. 865, except that the delay pellet was omitted. Much development work was done on other types such as electrically operated and aerodynamically armed fuzes, but none of these was ever used on operations.

The rocket projector

The provision of a suitable projector for aircraft rockets proved to be a more difficult matter than the modification of the Army 3-inch rocket. The Army projector was a heavy and clumsy affair, quite unsuitable for installation on an aircraft. A special projector for aircraft was designed by the R.A.E. and consisted of a 10 s.w.g. steel blast plate to protect the aircraft wing from damage due to rocket blast or burst motor. Under this plate were two rails—6 feet 8 inches long and the rocket was suspended from these rails by means of saddles attached to the front and rear of the motor. The rocket was prevented from moving forward by a lever, locked in position by a copper shear wire. The

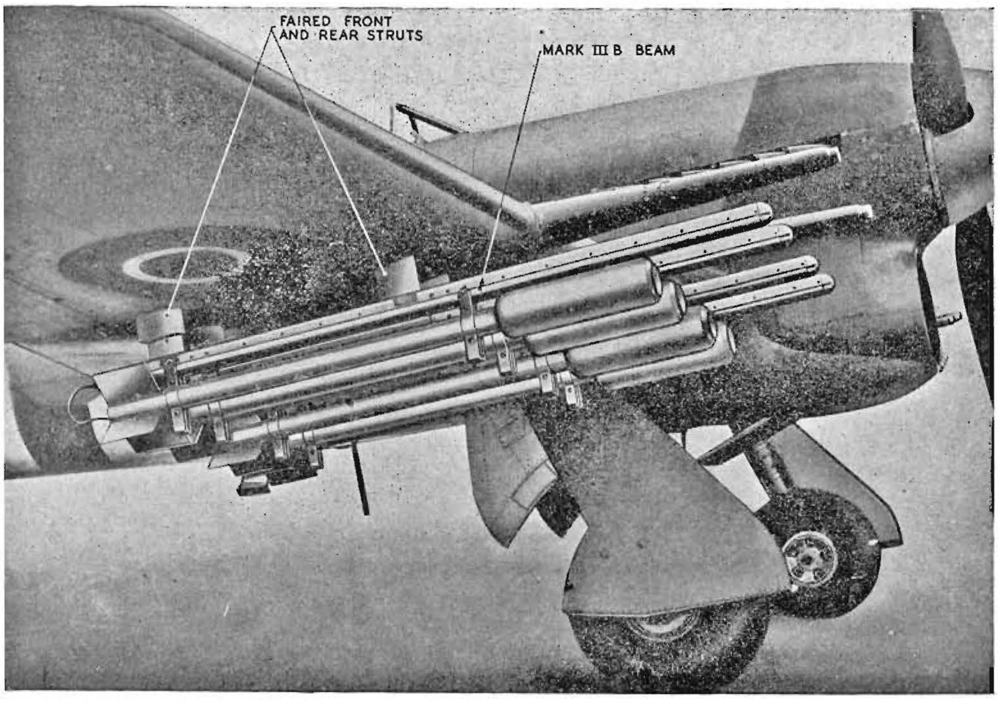
[1] A.M. File C.S. 12512/3.



Rocket Projectiles Fitted with Mark III Fins rockets were mounted in fours, and spaced $10\frac{1}{2}$ inches apart, with a common blast plate. They were fired electrically by the pilot, and could be fired either in one salvo of eight, or in four successive pairs. This projector was used for the first air firings from a Hurricane, which carried four under each wing.

In its production form it was known as the Mark I universal projector and was in full production by the beginning of 1943. It was widely used in operations on such aircraft as the Hurricane, Swordfish and Hudson. It worked well in service, but was heavy, and its high drag caused a considerable drop in the top speed of the aircraft carrying it. Most subsequent designs of projectors were intended to reduce the weight and drag of the installation rather than improve the performance as a projector. The Mark I was designed before any experience had been obtained with airborne rockets.

From subsequent air firing trials, it was concluded that the length of the projector rails could be greatly reduced. A projector, known as a ' Zero length ' projector, was produced in which the rocket was carried on two streamline struts and had a controlled travel of only a few inches. This was known as the Mark II projector, and was fitted experimentally on Swordfish and Hurricane aircraft. The drag, although reduced, was still considerable due to the retention of the blast plate. Ballistic trials of this projector showed that the dispersion was greater than with the Mark I, and as the reduction in drag was not considered worth the increase in dispersion, the Mark II projector was not put into production.



MARK IIIB BEAM INSTALLED ON TYPHOON AIRCRAFT AND LOADED WITH 60 LB. PRACTICE CONCRETE HEADS

Early in 1943, a third design commenced, based on the Mark I, and was intended to reduce the weight and drag and also to be easier to produce. The projector consisted of a single rail 7 feet 10½ inches long made from extruded light alloy sections. Experience with the Mark I had shown that the rocket blast would not damage the wing provided the rockets were carried not less than 9 inches from its under surface. In addition improvements in the manufacture of rocket motor tubes, and the introduction of cruciform cordite, had practically eliminated the chance of the rocket motor bursting. This new projector was introduced as Mark III and was used on Mosquito, Typhoon and Tempest aircraft. It was only half the weight of the Mark I and had considerably less drag.

During 1944, further experiments with zero length projectors were carried out and it was found that the extra dispersion was considerably reduced on high speed aircraft. A new type of zero length projector was therefore designed, known as the Mark VIII, and was put into production towards the end of the war but was not used on operations. It was only one quarter of the weight of the Mark III and had considerably less drag, making a reduction of only 4 m.p.h. in the top speed of a Tempest aircraft.

Increase in number of rockets carried

In the summer of 1944, an urgent request was made by 2nd T.A.F. for some means of increasing the number of rockets carried by fighter bombers. It was obviously impossible to carry out any drastic modification to the projector or aircraft at this stage, but by using a special type of double saddle, it was found that two rockets, one slung under the other, could be carried on the standard projector. This enabled the load of the fighter bomber to be increased from eight rockets to sixteen. In the first design the two rockets had to be fired together, but this was not altogether very satisfactory, and the saddle was further modified to enable the lower rocket to be fired independently of the upper rocket, the saddles acting as a zero length projector. This system was widely used during the operations in Europe during 1944 and 1945.

Other types of rocket

Although the 3-inch motor with the 60 lb. and 25 lb. heads were the only rockets used in operations, a considerable amount of experimental work was carried out on other designs, none of which had reached the production stage by the end of the war. Several schemes were investigated for using heavier heads than the 60 lb. H.E. propelled by several standard motors, among which was the firing of a 250 lb. G.P. bomb propelled by seven 3-inch motors. This was originally intended as an anti-shipping weapon and was abandoned in favour of the 'Uncle Tom' scheme. Some work was done on spin stabilised rockets, but development had not got very far by the end of the war.

'Uncle Tom'

In August 1944 the Air Staff formulated a requirement for a large calibre rocket for the attack of ships. After some investigation it was decided to develop a rocket consisting of a motor 10·25 inches diameter weighing 400 lb. to which was attached a head 10·5 inches diameter and weighing 600 lb. The complete rocket weighed approximately 1,030 lb. and had an overall length of 8 feet 8 inches. This weapon was given the code name 'Uncle Tom.' A considerable amount of experimental work was done on this project including under-water and air firing trials. It was still under development when the war ended.

CHAPTER 21

PYROTECHNICS

The science of pyrotechnics is of considerable antiquity and was known in the East, especially China, in very early times. The original use of fireworks was probably for spectacular purposes and also, possibly, for moral effect in warfare. The development of the projected firework, or rocket, led to its adoption for definite offensive incendiary action, and it was so employed in the British service in the early days of the 19th century. As guns improved, the war rockets fell into disuse, but were not finally recognised as obsolete until 1919.

Methods of ignition

Most pyrotechnic compositions used for illuminating or signal purposes are difficult to ignite. It is usual, therefore, to employ an additional composition, called ' priming ', which can more readily be ignited, and which burns at a sufficiently high temperature to ignite the main composition. Ignition is generally carried on in stages. Initiation is effected by an igniter or fuze, the flash produced then being conveyed to the priming composition either directly or, more usually, with the aid of quick match or safety fuze. When the function of the pyrotechnic involves the ejection of stars or flares from a container, a gunpowder charge is inserted between the fuze and priming.

Initiation can be carried out by several methods :—

(*a*) Friction igniters which operate on the principle of the common match and match-box. Either the match head or the match striker, usually the latter, is in intimate contact with the quick match or safety fuze.

(*b*) Electric igniters. These consist essentially of two poles connected together by a bridge of fine platinum-silver wire. The poles and bridge are secured in a paper or metal cylinder containing gunpowder dust. When an adequate electric current passes, the bridge fuzes and ignites the gunpowder dust.

(*c*) Percussion igniters. When a copper cap containing a mixture of mercury fulminate, potassium chlorate and antimony sulphide is struck a sharp blow, detonation takes place and a flash is produced which ignites the priming and main charge.

(*d*) Special igniters and fuzes.[1]

Pyrotechnic compositions

These are sub-divided according to their use into :—

(*a*) Illuminating Compositions. These are used for visual observations at night as they produce a bright light for a comparatively long period of time.

(*b*) Flash Compositions. These produce a very intense light for a very short period of time and are used for taking photographs at night.

(*c*) Signal Compositions. These produce a characteristic, usually coloured light for a period of time and are used for signalling purposes.

[1] A.H.B. Monograph, *Armament, Volume I, Bombs and Bombing Equipment, Part II, Chapter* 18. (S.D. 719.)

(*d*) Marine and Sea-Marker compositions. These are used for marking positions on water and are not true explosives. Marine marker compositions react with water to give off a gas which flames in air, giving a continuous flame. Sea-marker compositions produce a visible film on the surface of the water.

(*e*) Smoke Compositions. These produce either a dense opaque cloud for screening purposes, or a characteristic smoke for signalling in day-time. They are sub-divided into two types according to the method by which the smoke is produced.

(i) Burning smoke compositions. These generate smoke only after being ignited. The smoke may be produced either by direct action, as in oil smokes, or by the reaction of emitted volatile matter with the oxygen in the air.

(ii) Liquid non-burning smoke compositions. When certain liquids come into contact with the air in the form of very fine droplets, they form a smoke or mist due to reaction with the water vapour in the air.

Development

Various pyrotechnics were developed during the Second World War, the differences being mainly in the constituents used in the compositions to obtain

T.I. Bomb No. 14, Mark I

different effects.[1] The main advance in pyrotechnic development was in the design of various Target Indicator (T.I.) bombs for use of the Pathfinder Force (P.F.F.). The history of these stores will be dealt with more fully.

Pathfinder forces

In August 1942, an entirely new principle was applied to night bombing. The finding and marking of a target was the duty of a number of specially selected and trained crews whose task it was to provide a clearly visible aiming point for the main bomber force. This establishment was called the Pathfinder Force, and the numerous pyrotechnics developed for their use were referred to as P.F.F. Special Weapons. These weapons were produced in a great variety of pyrotechnic compositions and the enemy made every effort to produce imitations of each new pyrotechnic so that he might use decoy markers and divert the weight of bombs from vital targets. It was essential for the success of the pathfinder technique, that we had the lead in the design of each pyrotechnic device, and we always had this lead, even if at times it was only a short one. Between 1942 and the end of the war, over 40 different types of flares and marker bombs, in many different colour variations, were used.[2]

In the early stages of the development of this technique, standard 4·5-inch reconnaissance flares were dropped in very large quantities with the idea of providing sufficient illumination for the whole target area to enable the crews of following aircraft to select the exact aiming point. In order to provide still better concentration, large quantities of incendiary bombs were dropped to provide, as early as possible in the attack, large concentrated fires to act as an aiming point for the bomber crews. The 4-lb. incendiary bomb was supplemented by the benzol-rubber-phosphorous filled 250-lb. incendiary, and later a 4,000-lb. H.C. case was filled with a similar mixture but coloured so that the initial flash was of a brilliantly pink colour.

For certain types of target which were capable of being attacked by Oboe[3] aircraft, this method was supplemented by another technique—that of sky marking. This involved the dropping of coloured flares, some with stars of contrasting colours, used in various codes. Bombs aimed at these flares by aircraft flying on a fixed heading, would fall in the target area, and although this method could not give the accuracy of visual bombing, it did allow attacks to be made on nights when visual bombing was impossible owing to cloud cover.

The first Target Indicator (T.I.) bombs were dropped on 16 June 1943 during an attack on Berlin. These bombs, which were later developed in a variety of

[1] Main pyrotechnics introduced during the Second World War are given in Appendix 8.

[2] Types of 250-lb. T.I. bombs and their characteristics are given in Appendix 9.

[3] Basically the 'Oboe' blind bombing system comprised two fixed radar stations from which could be measured accurately the point at which a specially equipped aircraft should release its bombs to hit any selected target within the range of the stations. Signals from one station told the pilot if he was following the correct course, while the other station, after a series of preliminary warning signals, told the navigator exactly when to release his bomb. The name Oboe derived from early experiments when the sound of the signal in the special aircraft receiver was likened to the musical instrument.

types, formed the basis on which all ground marking techniques were built up. The T.I. bomb consisted, basically, of a bomb of good ballistic properties from which was ejected, at a set height above the ground, a number of pyrotechnic candles. Some of these were ignited as ejected and fell in a brilliantly illuminated cascade while others remained dormant for a period to ignite when the first candles were going out. The height of burst was controlled by a barometric fuze, which theoretically, irrespective of the height of release, ejected and ignited the contents at a given height above sea level.[1] The contents normally scattered over an area of about 100 yards diameter for each 250 lb. bomb. The difference that this bomb made was enormous, and together with Oboe, it may be justly said to have ensured the overwhelming success in the Battle of the Ruhr, the smoke and haze filled valleys of which had hidden so well the vital armament works they contained.

T.I. bombs were used initially in the double role of guides to approaching aircraft, and as indicators of the exact aiming point. Functioning at heights up to 9,000 feet or more, the cascade of burning candles was visible from great distances, and this was a feature that the enemy was never entirely successful in simulating, although he later produced some creditable imitations of the candles burning on the ground. In another form the 'Spot Fire,' the same bomb was extensively used for route marking, and in this form gave a single spot of red or green light of moderate intensity, to act as a sort of lighthouse to the great forces of aircraft on their long outward and homeward flights over occupied Europe. Explosive candles were introduced into the bomb to discourage fire fighters, and, at different times, various lengths of delay were incorporated in the pyrotechnic candles so that, at the expense of some intensity, the burning time of the marker could be of longer duration.

Yet another form consisted of 25 candles, each with its own parachute, giving a candelabra effect, and was mainly used for sky marking. It was, however, also used on a few occasions for illumination purposes ; in that application only the yellow colour proved effective.

Outside the range of Oboe, visual methods were, however, still needed. As a consequence a hooded flare was developed which succeeded in eliminating most of the upward glare experienced with the old 4·5-inch reconnaissance flare. At first used singly, a cluster mechanism was quickly developed for these flares which enabled the effective illumination of targets to be enormously increased in spite of a reduction in the total candle power employed. The clusters had to be assembled and filled with flares at stations and this work imposed a very severe additional strain on armament staffs. Each cluster took some 25 minutes to prepare, and as many as 90 clusters were used by a single squadron on one night, and the process repeated on the following nights as well.

As time went on, the enemy's attempts at simulation became more and more effective. The colours red, yellow and green were already in use as marking colours, and blue proved after a long series of experiments, to be impossible to obtain in sufficient intensity, tending always to be confused with the intense

[1] A.H.B. Monograph, *Armament, Volume I, Bombs and Bombing Equipment, Part II, Chapter* 18. (S.D. 719.)

white of the 4-lb. incendiary bomb. The only alternative course, therefore, was to swamp all such attempts to decoy, by employing markers in such quantity, or of such size, that no mistake was possible. Accordingly the 1,000-lb. T.I. bomb was developed to fill the Lancaster bomb stowage more economically. This bomb more than trebled the number of candles carried on each bomb station, and promised very well. Unfortunately as the defences of the targets were strengthened, so bombing heights were increased, and it was found that some weapons which had been ballistically stable and accurate from the lower heights, were far from satisfactory at the greater height. The 1,000-lb. T.I. was one of the worst sufferers in this respect.

The barometric fuze, specially designed to give operational freedom in height of attack to pathfinder crews, which had been used as a nose fuze, was now developed as a tail fuze with the idea of giving a greater range and greater accuracy of height. This tail version proved to be especially subject to interference from ballistic causes. An oscillating bomb was found to burst completely unpredictably as to height. These defects were partially overcome by the fitting of the long tail as originally designed for the 1,000-lb. H.E. bombs, and the continuation in use of the nose fuze (No. 860). This had the effect, however, of limiting the available load in a Lancaster to 6 × 1,000-lb. T.I.s plus 4 × 500-lb. bombs or 4 × 1,000-lb. T.I.s and 4 × 1,000-lb. bombs. As, however, the German decoy efforts became disorganized and sporadic, the necessity for 'swamping' was less acute.

From 'D-Day' onwards the need for markers for use by day became of increasing importance, and still more new versions of the T.I. bomb came to the fore as a result. In the early stages, smoke fillings were employed, especially yellow smoke, to mark targets, and later these same bombs were used as cancellation signs to countermand any markers that might fall in too close proximity to our own front line troops. A difficulty with these large scale day attacks was the vast clouds of dust and smoke which quickly obscured the whole target area, and the markers burning on the ground. To deal with this, and also to assist in blind bombing by day, a pigment-filled marker was produced which also met with considerable success. This left a puff of dust in the air which was remarkably distinctive and persistent. It could be used as an aiming mark in favourable conditions for over two minutes after functioning. Red, yellow, green and blue colours were available, and were selected according to the nature of the expected background.

Yet another version of the T.I. was in constant use by the Mosquito bomber force on their nightly visits to Berlin. This bomb, besides a reduced number of the usual pyrotechnic candles, also contained a photo-flash, and some remarkable photographs were obtained by this means from aircraft flying as high as 35,000 feet. These Mosquitos also had their own navigational problems, and a special route marker device was developed for them, consisting of a special signal cartridge of greater intensity and duration than the normal. This was produced in the usual three colours enabling turning points to be effectively marked without the risk of confusion, and more important still, without sacrificing a bomb station. Last of all the marking requirements was that for supply dropping operations. For these ordinary T.I. bombs were used from which the explosive candles had been removed.

The development and supply of P.F.F. pyrotechnic stores between 1942 and the end of the war was most satisfactory and contributed in no small degree to the increased effectiveness of Bomber Command. Although these stores were used primarily by No. 8 (P.F.F.) Group, many of them were also widely used by all the main force groups.

APPENDIX I

FRAZER NASH TURRETS

Serial Number.	Position in Aircraft.	Aircraft Type.	Number and type of guns.	Calibre.	Rounds per gun carried.	Total Weight approx. including gunner. (lb.)	Power System.	Remarks.
FN.1	Upper	2 seat fighter	One L	·303	400	427	Hydraulic	Originally fitted with telescopic cowling; cupola added later.
FN.2	Upper	2 seat fighter	One VGO	·303	300	425	Hydraulic	Not required for service use.
FN.3	Upper	N.A.	Four B	·303	N.A.	N.A.	N.A.	Experimental only.
FN.4	Tail	Bomber and Flying boat	Four B	·303	1,000	950	Hydraulic	Nil.
FN.5	Nose or tail	Bomber	Two B	·303	1,000 or 2,000	670 or 1,300	Hydraulic	Ammunition carried and approximate weight varied according to whether nose or tail.
FN.6	Nose	N.A.	Two B	·303	N.A.	N.A.	N.A.	Experimental only.
FN.7	Upper	Bomber	Two B	·303	1,000	690	Hydraulic	Nil.
FN.8	Upper	Flying boat	Two B	·303	1,000	750	Hydraulic	Could be retracted into hull.
FN.9	Under	Bomber	Two B	·303	1,000	820	Hydraulic	Developed to prototype stage only.
FN.10	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	Experimental project. Cancelled in early stages.
FN.11	Nose	Flying boat	One VGO	·303	300	400	Hydraulic	Could be retracted rearwards for mooring operations, *See also* FN.16.
FN.12	Nose	Flying boat	One twin VGO	·303	400	480	Hydraulic	Few produced. *See* FN.26.
FN.13	Tail	Flying boat	Four B	·303	500	700	Hydraulic	Nil.
FN.14	Nose	Bomber	One L	·303	100	380	Hydraulic	Similar to FN.15 except that bombsight fitted instead of second gun.
FN.15	Tail	Bomber	Two L	·303	200	420	Hydraulic	Nil.
FN.16	Nose	Bomber	One VGO	·303	300	450	Hydraulic	Identical with FN.11 but not retractable.
FN.17	Under	Bomber	Two B	·303	1,000	800	Hydraulic	Retractable.
FN.18	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	Experimental only. Cancelled in early stages.
FN.19	Under	Bomber	Two B	·303	2,000	1,000	Hydraulic	Developed to prototype stage only.
FN.20	Tail	Bomber	Four B	·303	2,500	1,460	Hydraulic	Servo ammunition feed and protective armour.
FN.21	Under	Bomber	Two B	·303	2,000	830	Hydraulic	Developed to prototype stage only.
FN.22 FN.23 FN.24	} N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	Experimental only. Cancelled in early stages.

FN.25	Under	Bomber	Two B	·303	1,000	780	Hydraulic	Retractable similar to FN.17.
FN.26	Nose	Flying boat	One VGO	·303	1,000	550	Hydraulic	Similar to FN.12 except that single VGO gun fitted.
FN.27	Upper	Bomber	Two H	20 mm.	600	1,554	Hydraulic	Experimental only.
FN.28	Upper	N.A.	Two COW	37 mm.	480	2,121	Hydraulic	Experimental only.
FN.29	Under	N.A.	Two H	20 mm.	120	1,670	Hydraulic	Experimental only.
FN.30	Upper	N.A.	Four H	20 mm.	150	2,720	Hydraulic	Experimental only.
FN.31	Under	N.A.	Four H	20 mm.	150	2,600	Hydraulic	Experimental only.
FN.32	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	Experimental only. Cancelled at an early stage.
FN.33	Upper	N.A.	Four B	·303	1,000	1,000	Hydraulic	Experimental only.
FN.34	Upper	N.A.	One B	·303	N.A.	N.A.	N.A.	Experimental only. Cancelled in early stages.
FN.35	Upper	N.A.	Two B	·303	1,000	700	Hydraulic	Experimental only.
FN.36	Upper	Flying boat	Four B	·50	1,000	2,080	Electro-Hydraulic	Experimental only.
FN.37	N.A.	N.A.	One H	20 mm.	N.A.	N.A.	N.A.	Experimental only.
FN.38	Upper	Bomber	Two B	·50	500	1,570	Hydraulic	Experimental only.
FN.39	Under	Bomber	Two H	20 mm.	N.A.	N.A.	N.A.	Experimental only.
FN.40	Under	Bomber	Two H	20 mm.	400	1,754	Hydraulic	Experimental only.
FN.41	Under	Bomber	Two B	·50	550	1,090	Hydraulic	Experimental only.
FN.42	Tail	Bomber	Two B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.43	Under	N.A.	Two or Four B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.44	Under	Bomber	Two or Four B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.45	N.A.	N.A.	Two B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.46	Tail	N.A.	Two B	·50	70	950	Hydraulic	Experimental only.
FN.47	Tail	N.A.	One H	20 mm.	N.A.	N.A.	N.A.	Experimental only.
FN.48	Upper	N.A.	Two B	·303	1,000	690	Hydraulic	Experimental only.
FN.49	Upper	N.A.	Two B	·303	1,000	700	Hydraulic	Experimental only.
FN.50	Upper	Bomber	Two B	·303	1,000	700	Hydraulic	Developed from FN.5.
FN.51	Under	N.A.	Two B	·50	700	1,380	Hydraulic	Experimental only.
FN.52	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	Experimental only. Cancelled in early stages.
FN.53	Upper	Bomber	Two B	·303	500	N.A.	Manual	Hand operated gun mounting.
FN.54	N.A.	N.A.	Two B	·303	1,000	N.A.	Manual	Hand operated. Developed to prototype only.
FN.55	Beam	Bomber	Two B	·303	1,000	N.A.	Manual	Hand operated gun mounting.
FN.56	Beam	Bomber	One B	·303	500	N.A.	Manual	Hand operated gun mounting.
FN.57	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	No records available.
FN.58	Under	N.A.	Two B	·303	1,000	N.A.	N.A.	Experimental only.
FN.59	Tail	Flying boat	Four B	·50	1,000	3,030	Electro-Hydraulic	Developed to prototype stage only.
FN.60	Under	Bomber	Two B	·303	1,000	N.A.	Manual	Hand operated gun mounting.
FN.61	Under	Bomber	Two B	·303	1,000	N.A.	Manual	Hand operated gun mounting.

APPENDIX 1—*continued*

Serial Number.	Position in Aircraft.	Aircraft Type.	Number and type of guns.	Calibre.	Rounds per gun carried.	Total weight approx. including gunner. (lb.)	Power system.	Remarks.
FN.62	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	Experimental only. Cancelled in early stages.
FN.63	Under	N.A.	Two B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.64	Under	Bomber	Two B	·303	750	530	Hydraulic	Nil.
FN.65	Upper	N.A.	Four B	·303	N.A.	N.A.	N.A.	Experimental only.
FN.66	Nose	Flying boat	Four B	·50	300	1,950	Electro-Hydraulic	Developed to prototype stage only.
FN.67	Upper	N.A.	Four B	·303	1,000	N.A.	N.A.	Experimental only.
FN.68	Nose	N.A.	One H	20 mm.	N.A.	N.A.	N.A.	Experimental only.
FN.69	Nose	N.A.	Two B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.70	Tail	N.A.	Two B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.71	Upper	Bomber	Six B	·303	1,000	N.A.	N.A.	Remote control. Developed to prototype stage only.
FN.72	Upper	Bomber	Six B	·303	1,000	N.A.	N.A.	Improved FN.71. Developed to prototype stage only.
FN.73	Tail	Bomber	Four B	·303	N.A.	N.A.	N.A.	Experimental only. Pressurized for high altitude.
FN.74	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	Experimental only. Cancelled in early stages.
FN.75	Nose	Flying boat	One S	40 mm.	N.A.	N.A.	N.A.	Experimental only.
FN.76	Upper	N.A.	Two B	·50	600	N.A.	N.A.	Experimental only.
FN.77	Under	Bomber	N.A.	N.A.	N.A.	500	Hydraulic	Leigh-Light (searchlight).
FN.78	Nose	N.A.	Two B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.79	Upper	Bomber	Two H	20 mm.	200	1,350	Hydraulic	Twelve only produced, for operational trials by Bomber Command.
FN.80	Nose	N.A.	Two B	·50	N.A.	N.A.	N.A.	Remote control. Experimental only.
FN.81	Nose	N.A.	Four B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.82	Tail	Bomber	Two B	·50	1,250	1,700	Hydraulic	Electric ammunition feed, gyro gunsight and radar attachment.
FN.83	Upper	N.A.	Four B	·303	N.A.	N.A.	N.A.	Experimental only.
FN.84	Under	N.A.	Two B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.85	Tail	N.A.	Two H	20 mm.	N.A.	N.A.	N.A.	Experimental only.
FN.86	N.A.	N.A.	Two H	20 mm.	420	N.A.	N.A.	Hand operated, ground defence gun mounting.
FN.87	N.A.	N.A.	Four H	20 mm.	600	N.A.	N.A.	Hand operated, ground defence gun mounting.
FN.88	Beam	Bomber	One B	·50	450	N.A.	Manual	Hand operated gun mounting.
FN.89 to FN.93	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	All these were experimental only and cancelled in the early stages.

FN.94	Beam	N.A.	One B	·50	N.A.	N.A.	Hydraulic	Nil.
FN.95	Upper	Bomber	Two B	·50	300	770	Hydraulic	Remote control. Developed to prototype stage only.
FN.96	Upper	Bomber	Two B	·50	N.A.	N.A.	N.A.	Experimental only.
FN.97 to FN.119	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	These serial numbers had not been allocated during the period covered by this monograph.
FN.120	Tail	Bomber	Four B	·303	2,500	1,470	Hydraulic	Modified FN.20. Improved field of vision.
FN.121	Tail	Bomber	Four B	·303	2,500	1,550	Hydraulic	Replaced FN.120. Electric ammunition feed, gyro gunsight and radar attachment.
FN.122	Tail	Bomber	Four B	·303	2,500	1,490	Hydraulic	Same as FN.121 but no radar attachment. Not produced.
FN.123	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	Project similar to FN.122. Abandoned in favour of FN.121.
FN.124 to FN.149	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	These serial numbers had not been allocated during the period covered by this monograph.
FN.150	Upper	Bomber	Two B	·303	1,000	720	Hydraulic	Modified FN.50. Improved field of vision, plus gyro gunsight and radar attachment.
FN.151 to FN.219	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	These serial numbers had not been allocated during the period covered by this monograph.
FN.220	Tail	Bomber	Two B	·303	1,000	670	Hydraulic	Modified FN.20. Improved field of vision. Developed to prototype stage only.

Abbreviations

L = Lewis gun.
B = Browning gun.
VGO = Vickers gas operated gun.
H = Hispano gun.
S = Vickers 'S' gun.
COW = Coventry Ordnance Works gun.
N.A. = Not applicable or no reliable information available.

APPENDIX 2

FN. 77 TURRET

The FN.77 was a retracting searchlight turret, installed in the mid-under position of an aircraft. The extension from, and retraction into the airframe, was controlled locally but the manipulation of the searchlight was controlled remotely by an operator in the nose of the aircraft. The position of the searchlight, relative to horizontal and vertical datums, was transmitted to the operator by an electrical indicator system.

Mechanical action of the turret was attained by hydraulic power, using three circuits :—

(*a*) Rotation.

(*b*) Elevation and Depression.

(*c*) Retraction and Extension.

Circuits (*a*) and (*b*) were pressure circuits, powered by an engine driven pump. Circuit (*c*) was a static circuit operated manually by hand pumps.

Two electrical services were used :—

(*a*) Searchlight illumination system.

(*b*) Indicator system.

Turret Structure

A circular drum containing the searchlight was attached to a rotating ring which revolved on ball bearings, running on a fixed ring. A hydraulic motor mounted on the rotating ring, provided the rotational drive to the turret, through a pinion fitted to the motor spindle and engaging with a circular gear rack, secured to the fixed ring.

Stationary retraction guide bars, mounted in the airframe, carried a superstructure mounted on the fixed ring, and supported the entire turret. The upper ends of the superstructure were spanned by the turret bridge.

Hydraulic components

A relief valve, to prevent excess pressure in the hydraulic system, was fitted between the engine driven pump and the valve box in the nose of the aircraft. To feed the oil from the rigid pipe lines in the airframe to the rotating portion of the turret, two rotating service joints were used ; one rotating service joint (upper) for feeding the oil to the hydraulic motor for the rotation of the turret, and the other rotating service joint (lower) for feeding the oil to the ram for the elevation and depression of the searchlight.

Two hand pumps on the superstructure of the turret were used to operate the static oil system for extending and retracting the turret. A reservoir in the circuit ensured an adequate supply of oil for the retraction rams. The turret lowered under its own weight, but the hand pumps could be used to expedite lowering.

Safety measures

A safety catch mechanism, to anchor the turret in its retracted position, was fitted and was operated by a lever on the starboard side of the turret bridge. Above this lever was a rotation stop valve, to prevent the turret being rotated during servicing.

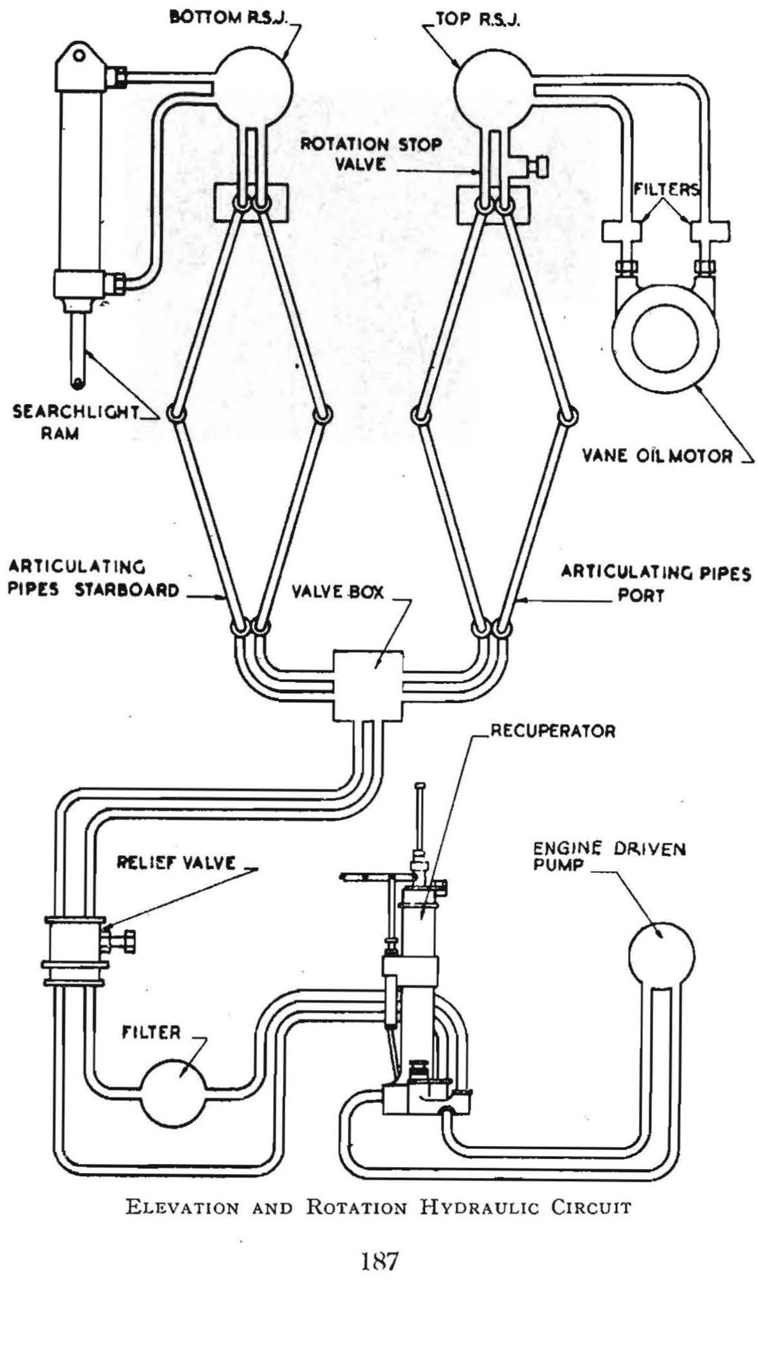
The searchlight compartment was isolated by a fireproof diaphragm, and ventilated by an extraction fan. The ventilation was adjusted by a movable baffle ring, which varied the size of the holes in the drum.

A block and tackle was provided in the airframe, immediately above the turret, for hand retraction of the turret in the event of an emergency.

External hydraulic system

Hydraulic power for operating the searchlight installation, was obtained from an engine driven pump. From the supply side of the pump, the oil passed through a relief valve to the valve box in the nose of the aircraft and the system was then divided into two circuits ; the elevation and depression, and rotation of the searchlight. These two circuits supplied oil to the rotating service joints on the turret bridge. The oil returned from the exhaust ports of the rotating service joints, through a recuperator mounted close to the engine driven pump, to the return side of the pump.

When the master valve levers, on the control handles mounted above the valve box, were in their normal position, the oil by-passed direct to the return pipe without entering the rotation and elevation valves, allowing a ' free flow ' condition in the system. When the master valve levers were depressed, and the control handles not moved about either their vertical or horizontal axes the return line was isolated from the supply line and pressure was built up in the system. When this pressure exceeded the working pressure of the turret, the relief valve was operated. The pressure was maintained until the controls were operated. The pressure was maintained until the controls were operated for either turret drum rotation, or elevation or depression of the searchlight.



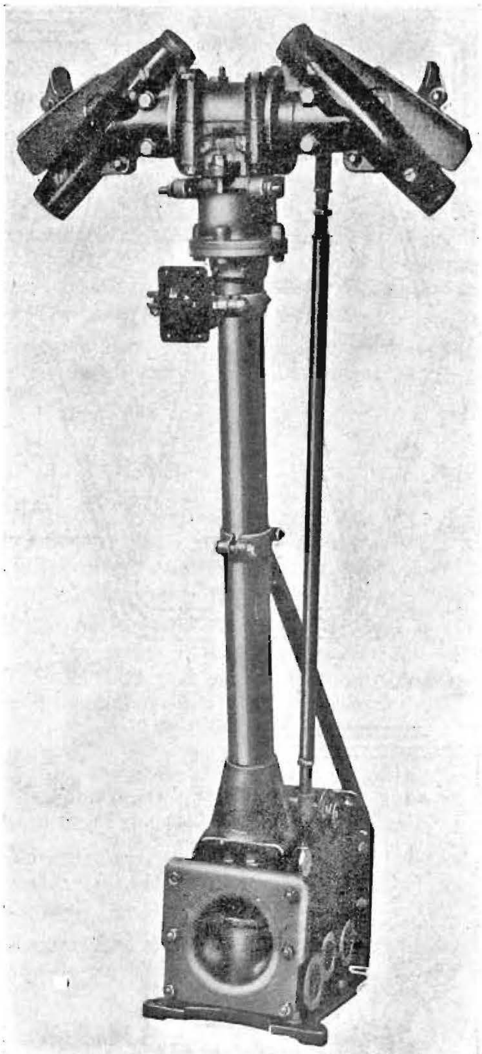
Elevation and Rotation Hydraulic Circuit

Internal hydraulic system

There were two hydraulic circuits inside the turret, *i.e.*, rotation and elevation and depression of the searchlight. In both these circuits, rigid pipe lines fed the oil from the inlet port of the two rotating service joints, direct to the hydraulic components.

The first circuit supplied oil through a hydraulic filter to one of the ports of the hydraulic motor. The action of this motor rotated the turret drum and searchlight in one direction. If oil was supplied to the other port of the motor, the turret drum and searchlight were rotated in the opposite direction.

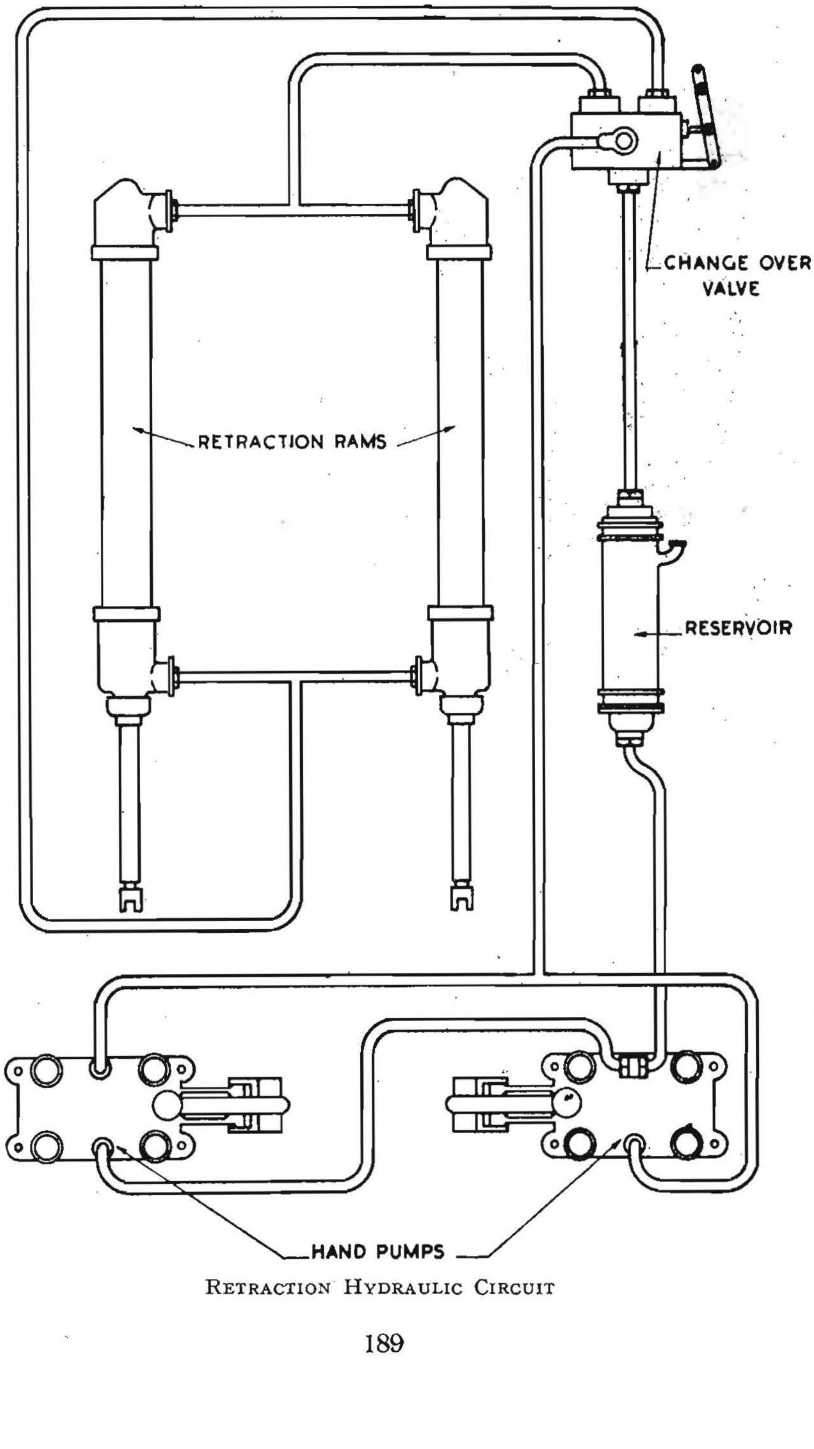
The second circuit supplied oil to a double acting ram, which was mounted in the searchlight chamber and coupled to a lever on the side of the searchlight. The movement of this ram, up or down, elevated or depressed the searchlight beam.



VALVE BOX AND CONTROL HANDLES

Retraction system

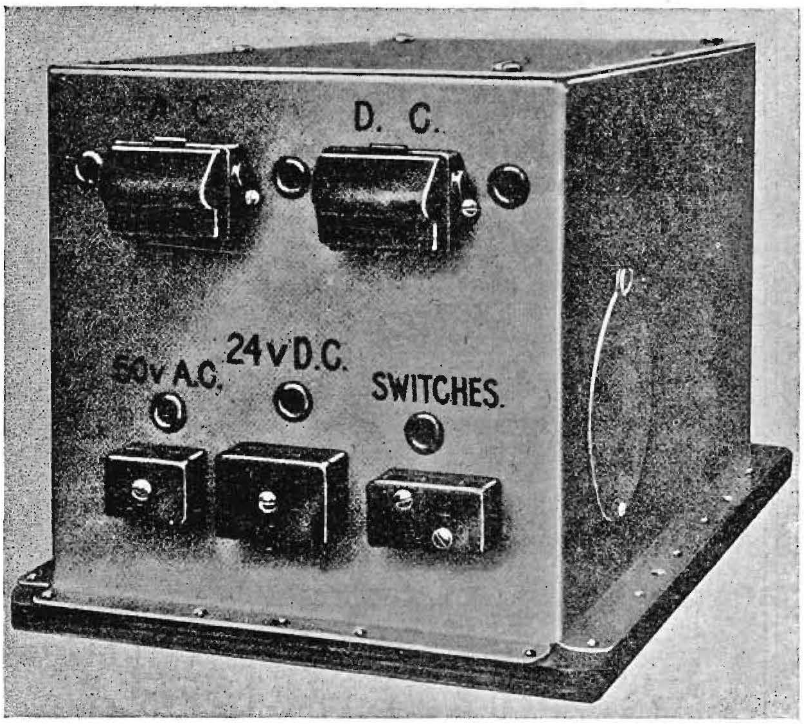
External to the turret was the retraction hydraulic circuit. This was a static circuit consisting of two double acting rams, which were fed with oil, pumped from a reservoir by hand pumps. In the supply line of the circuit was a change-over valve which directed the oil to either the top or bottom ports, of the double acting rams. When oil entered the bottom ports, the rams were forced upwards and the turret was retracted into the airframe. Operation of the change-over valve released the pressure built up in the rams, and the turret lowered under its own weight. One, or both, of the hand pumps could be used to expedite lowering.



RETRACTION HYDRAULIC CIRCUIT

Electrical system

The turret had two electrical systems; searchlight illumination and indicator. The searchlight was a standard Admiralty searchlight. It was self-striking and self-regulating and could be serviced in flight; access being gained through a door in the diaphragm. The searchlight was powered by a bank of seven 12-volt batteries in series, mounted in the airframe. The controls were situated on a panel, mounted in the airframe, adjacent to the turret but to prevent unnecessary wastage of current, a switch was fitted in the nose of the aircraft at the side of the operator, so that he could switch the searchlight on or off as required.



ROTARY CONVERTER UNIT

An accurate indication of the position of the rotating drum and searchlight was obtained by a system of remote electrical indicators. The current for this system (50 volt, 50 cycles per second, single phase A.C.) was provided by a rotary converter, located in the centre of the aircraft on the starboard side and fed by two of the searchlight batteries. The turret contained elevation and rotation transmitters, suitably geared to the appropriate components, which transmitted electrically, the position of the searchlight relative to vertical and horizontal datums, to indicator dials in front of the operator. The rotary convertor could be switched on or off, from the nose of the aircraft.

APPENDIX 3

RÉSUMÉ OF THE AIR MINISTRY SPECIFICATION FOR A STANDARD REMOTE CONTROL SYSTEM

(*a*) General requirements

(i) The complete system was to consist of an upper sighting station, controlling an upper barbette, through the medium of a British Thomson Houston electric link.

(ii) The sighting station was to be fully rotatable and fitted with a gyro-gunsight, having an A.G.L.T. attachment.

(*b*) Upper Barbette

(i) To be fitted with two 20-mm. Hispano guns.

(ii) To be capable of continuous rotation through 360 degrees, in either direction.

(iii) Interruption gear to be fitted to prevent the guns being aimed at any part of the aircraft in which crew might be stationed, or firing at any part of the aircraft structure.

(iv) When the gunner ceased to use the gunsight, the guns were to return automatically, to a neutral position pointing dead astern, and to be locked so as to prevent movement during aircraft manoeuvres.

(v) The rotation planes of the barbette and sighting station were to be parallel in order to simplify sighting arrangements.

(*c*) Upper sighting station

(i) To be fitted with a gyro-gunsight with A.G.L.T. attachment, Frazer Nash control handles, adjustable seat and certain other parts of the A.G.L.T. equipment.

(ii) The minimum field of view was to be 360 degrees in azimuth, 90 degrees in elevation and 20 degrees depression on either beam. A direct vision panel was to be provided, for use at night.

(iii) The best possible arrangements were to be made for the comfort of the gunner. Adequate heating and ventilation were required, both to be controllable by the gunner.

(iv) The gunner's seat to be adjustable both vertically and fore and aft, so as to accommodate a man of any size comfortably. A secondary position, higher than normal, was to be provided in order to give the maximum possible field of view when the gunsight was not in use.

(v) Internal lighting was to be controllable ultra-violet so as to reduce glare and reflection to a minimum.

(vi) The station was to be fully rotatable, under power or manually as required.

(*d*) Remote control link

(i) The electrical system was to be capable of producing smooth operations with a complete absence of hunt or jerk.

(ii) Circuits were to be duplicated wherever possible, and means provided for changing over from normal to emergency circuits. The change over was to be automatic, if possible.

(iii) The overall accuracy of the link was to be such that the error between the sight and guns, did not exceed 8 minutes of arc at a speed of 15 degrees per second, or 15 minutes of arc at 20 degrees per second.

(e) Control

(i) The system was to be 'rate'[1] controlled.

(ii) At maximum control handle displacement, speeds in the horizontal and vertical planes were to attain a maximum of 60 degrees per second and 35 degrees per second, respectively.

(iii) Response to control handle movement was to be instantaneous.[2]

(f) Operating conditions

All components were required to operate efficiently at :—

(i) An ambient air temperature of $\pm$ 50° C.

(ii) An atmospheric relative humidity of 100 per cent.

(iii) A maximum aircraft speed of 400 m.p.h. at 35,000 feet.

(iv) An aircraft attitude of 15 degrees climbing and 30 degrees diving.

(v) Accelerations of :—

2½ G downwards.

1½ G in all other directions.

(g) Stressing conditions

All components were to operate efficiently after, but not necessarily during, the following conditions of stress :—

(i) A maximum aircraft speed of 450 m.p.h.

(ii) Accelerations of :—

5½ G downwards

2½ G upwards.

2 G sideways.

3 G backwards or forwards.

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[1] R.A.E. Report No. Arm. 203 dated April 1948

[2] Control may be applied in one of three ways :—

(a) Rate Control—Guns move at a rate depending on control handle displacement.

(b) Position Control—Gun position bears a direct relationship to control handle position.

(c) Aided Lay Control—A combination of (a) and (b) above.

APPENDIX 4

BOULTON PAUL TURRETS

Serial Number.	Position in Aircraft.	Aircraft Type.	Number and type of guns.	Calibre.	Rounds per gun carried.	Total weight approx. including gunner. (lb.)	Power system.	Remarks.
A Mark I	Upper	—	Four B	·303	—	—	Electro-hydraulic 1,200 lb. sq. in. Rotation.900 lb. sq. in. elevation.	Original basic design only.
A Mark IID	Upper	Fighter	Four B	·303	600	830	As above	Nil.
A Mark IIR	Upper	—	Four B	·303	600	830	As above	Nil.
A Mark II P.B. 1 and 2	Not installed in any type of aircraft. Fitted in motor fishing smacks in positions as required.		Four B	·303	600	849	As above	Nil.
A Mark II S. 1 and 2	Upper	'G' class flying boats	Four B	·303	600	813	As above	Nil.
A Mark II S.5	Tail	'C' class flying boats	Four B	·303	600	807	As above	Nil.
A Mark III	Upper	Bomber	Four B	·303	600	813	As above	Limited number manufactured.
A Mark IV	Upper	Heavy bomber	Four B	·303	600	813	As above	Limited number manufactured.
A Mark V	Upper	Medium bomber	Four B	·303	600	813	As above	Limited number used in Middle East.
A Mark VA	Upper	Medium bomber	Four B	·303	600	813	As above	Differed from the Mark V in its elevation and depression angle (74 degrees elevation and 10 degrees depression).
A Mark VI	Upper	Medium bomber	Four B	·303	600	813	As above	Nil.
A Mark VII	Upper	—	Four B	·303	600	813	As above	Did not go into production. Similar to Mark IIR
A Mark VIII Standard	Upper	Heavy bomber	Four B	·303	550	799	As above	74 degrees elevation 2½ degrees depression.
A Mark VIII Special	Upper	Heavy bomber	Four B	·303	550	799	As above	Limited number made by conversion of other Type A turrets.
No Mark alloted	Upper	—	Four B	·303	600	930	—	Amplidyne controlled. Experimental only. (Late 1943.)
B Mark I	Upper	Heavy bomber	Four B	·303	—	—	Electro-hydraulic Rotation 1,200 lb. per sq. in. Elevation 750lb.	Experimental only.

APPENDIX 4—*continued*

Serial Number.	Position in Aircraft.	Aircraft Type.	Number and type of guns.	Calibre.	Rounds per gun carried.	Total weight approx. including gunner. (lb.)	Power system.	Remarks.
C Mark I	Nose	Heavy bomber	Two B	·303	1,000	709	As above	Field of fire 100 degrees each side of aircraft centre line, 60 degrees elevation 45 degrees depression. Low pressure oxygen from aircraft supply.
C Mark II	Upper	General reconnaissance	Two B	·303	1,000	782	As above	Continuous rotation. Oxygen supply in turret.
C Mark IIA	Upper	As above	Two B	·303	1,000	782	As above	Differed from Mark II in oxygen supply.
C Mark IIB	Upper	As above	Two B	·303	1,000	782	As above	Modified IIA for use at low temperature.
C Mark III	Upper	As above	Two B	·303	1,000	782	As above	No production.
C Mark IV	Upper	Bomber	Two B	·303	1,000	782	As above	Production finished 1944.
C Mark V	Upper	Heavy bomber	Two B	·303	1,000	782	As above	Limited production only replaced by Type A Mark VIII.
D Mark I	Tail	Heavy bomber	Two B	·5	1,100	1,613	Electro-hydraulic 1,750 lb. per sq. in.	Servo feed track boosters.
D Mark II	Tail	Heavy bomber	Two B	·5	1,100	1,613	As above	Turret modified to take scanner.
E Mark I Series I	Tail	Heavy bomber	Four B	·303	2,500	1,514	Electro-hydraulic 1,200 lb. per sq. in.	Nil.
E Mark I	Tai	Heavy bomber	Four B	·303	2,500	1,514	As above	Servo feed electric.
E Mark I Series 2A	Tail	General reconnaissance	Four B	·303	2,500	1,534	As above	Servo feed electric. Gyro gunsight Mark IC. (Coastal Command only.)
E Mark II	Tail	Heavy bomber	Four B	·303	2,500	1,514	Electro-hydraulic 1,200 lb. per sq. in. rotation 900 lb. per sq. in. elevation.	Nil.
E Mark IIA	Tail	Heavy bomber	Four B	·303	2,500	1,534	As above	Fitted with gyro gunsight Mark IC.
E Mark IIB	Tail	Heavy bomber	Four B	·303	2,500	1,514	As above	Modified for Bomber Command.
E Mark III	Tail	Heavy bomber	Four B	·303	2,500	1,514	As above	Improved cupola (modified Type E Mark I Series 2).
E Mark III	Tail	Heavy bomber	Four B	·303	2,500	1,514	As above	Fitted with gyro gunsight Mark IIC. Further improvements to cupola.

F Mark I	Nose	Aircraft with ideal nose	Two B	·5	250	560	As above	Operated from bomb aimer's position.
G Mark I	Nose	Heavy bomber	One B	·5	300	—	—	Abandoned at mock up stage in favour of F Mark I.
H Mark I	Upper	Heavy bomber	Two H	20 mm.	300	1,350	Electro-hydraulic 1,250 lb. per sq. in.	Prototype only. Rotation 45 degrees each side of centre line of aircraft 50 degrees elevation, 9 degrees depression.
K Mark I	Under	Heavy bomber	Two B	·303	1,000	918	—	Nil.
K Mark II	Under	—	Two B	·303	1,000	936	—	Nil.
H Mark I	Upper	—	One H	20 mm.	15 round drums as required	—	—	Experimental only.
R Mark I	Under	—	Two B	·303	1,000	—	—	Prototype only.
R Mark II	Under	—	Two B	·303	1,000	—	—	Tooling for production completed then dropped.
S Mark I	Tail	—	Two B	·5	650	—	—	Developed to specification, but did not go into production.
T Mark I	Under	—	Two B	·5	600	—	—	As above.
U Mark I	Under	—	Two B	·5	—	—	—	As above.
V Mark I	Nose	—	Two B	·5	—	—	—	As above.

Abbreviations

B = Browning gun. H = Hispano gun. NA = Not applicable or no reliable information available.

APPENDIX 5

BRISTOL TURRETS

Type.	Position in Aircraft.	Aircraft Type.	Number and type of guns.	Calibre.	Rounds per gun carried.	Total weight approx. including gunner. (lb.)	Power system.	Remarks.
B.I Mark I	Upper	Bomber	One L	·303	1,650	523	Hydraulic (700 lb. per sq. in.)	Nil.
B.I Mark IE	Upper	Bomber	One VGO	·303	1,700	541	As above	Nil.
B.I Mark II	Upper	Bomber	One L	·303	1,650	523	As above	Nil.
B.I Mark III	Upper	Bomber	One VGO	·303	1,700	541	As above	Nil.
B.I Mark IV	Upper	Bomber	Two B	·303	950	564	As above	Two rotation rams.
B.I Mark IVF	Upper	Bomber	Two B	·303	950	564	As above	Forward firing version of Mark III. Not produced.
B.I Mark V	Upper	Bomber	Two B	·303	950	668	Hydraulic (800 lb. per sq. in.)	Converted from Mark IV.
B.I Mark VI	Upper	Bomber	Two B	·303	960	577	Hydraulic (550 lb. per sq. in.)	Converted from Mark V.
B.II Mark I	Nose	Bomber	One VGO	·303	600	377	Hydraulic (600 lb. per sq. in.)	Nil.
B.III Mark I	Tail	Bomber	One VGO	·303	600	382	As above	Nil.
B.IV Mark I	Upper	Bomber	One VGO	·303	2,000	566	Hydraulic (800 lb. per sq. in.)	Nil.
B.IV Mark IE	Upper	Bomber	Two VGO	·303	1,000	583	As above	Nil.
B.IV Mark II	Upper	Bomber	Two B	·303	600	513	As above	Nil.
B.V Mark I	Upper	Bomber	One VGO	·303	1,000	N.A.	N.A.	Experimental only. Cancelled in early stages.
B.VI Mark I	Upper	N.A.	Two H	20 mm.	60	N.A.	N.A.	As above.
B.VII Mark I	Upper	N.A.	Two H	20 mm.	60	N.A.	N.A.	As above.
B.VIII Mark I	Upper	Bomber	Four H	20 mm.	1,200	N.A.	N.A.	As above.
B.IX Mark I	Upper	Bomber	Four H	20 mm.	1,200	N.A.	N.A.	As above.
B.X Mark I	Upper	Bomber	Two B	·303	1,300	894	Hydraulic (800 lb. per sq. in.)	Rotation rams replaced by motor.
B.X Mark II	Upper	Bomber	Two B	·303	1,300	894	Electric	Experimental only.
B.XI Mark I	Upper	Bomber	Four B	·303	650	759	Hydraulic (800 lb. per sq. in.)	Developed from B.I Mark IV, to prototype stage only.

B.12	Mark I	Upper	Bomber	Four B	·303	1,000	1,152	Hydraulic (850 lb. per sq. in.)	First turret to carry four guns.
B.12	Mark II	Upper	Bomber	Two B	·50	690	1,485	As above	Developed to prototype stage only. Cancelled in favour of B.17 Mark I.
B.12	Mark III	Upper	N.A.	Four B	·303	1,000	1,159	Electric	Developed to prototype stage only.
B.12	Mark IV	Upper	Bomber	Four B	·303	1,000	1,159	Hydraulic (850 lb. per sq. in.)	Developed to prototype stage only.
B.12	Mark V	Upper	Bomber	Four B	·303	1,000	1,159	As above	Nil.
B.13	Mark I	Under	Bomber	Two B	·303	800	371	Hydraulic (350/400 lb. per sq. in.)	Developed to prototype stage only.
B.14	Mark I	Nose	Bomber	Four B	·303	1,000	N.A.	Manual	Developed to prototype stage only.
B.15	Mark I	Upper	Bomber	Four B	·303	500	848	Hydraulic (800 lb. per sq. in.)	Experimental only.
B.16	Mark I	Nose	Bomber	One S	40 mm.	66	1,160	Electric	Experimental only.
B.17	Mark I	Upper	Bomber	Two H	20 mm.	350	1,681	Electric	Nil.
B.17	Mark II	Upper	Bomber	Two H	20 mm.	350	1,681	Electric	Nil.
B.18	Mark I	Tail	Bomber	Two H	20 mm.	600	N.A.	N.A.	Experimental only. Cancelled in early stages.
B.19	Mark I	Tail	N.A.	Four B	·50	N.A.	N.A.	N.A.	As above.
B.20	Mark I	Upper	Bomber	One B	·303	500	N.A.	Manual	Nil.
B.21	Mark I	Upper	Bomber	One B	·50	500	N.A.	Manual	Nil.
B.22	Mark I	Under	Bomber	Two B	·50	N.A.	N.A.	Manual	Experimental only.
B.23	Mark I	Tail	Bomber	Two B	·50	500	N.A.	Electric	Semi-remote control. Experimental only.
B.24	Mark I	Tail	N.A.	Two H	20 mm.	N.A.	N.A.	Electric	As above.
B.25	Mark I	Tail	N.A.	Two H	20 mm.	N.A.	N.A.	Electric	Experimental only.
B.26	Mark I	Upper	Bomber	Two B	·50	300	N.A.	N.A.	Semi-remote control. Experimental only.
B.27	Mark I	Beam	Bomber	One B	·50	300	N.A.	Manual	Nil.
B.28	Mark I	Beam	Bomber	One B	·50	300	N.A.	Manual	Nil.
B.29	Mark I	Upper	N.A.	One H	20 mm.	300	831	Electric	Experimental only.
B.30	Mark I	Upper	Bomber	Two H	20 mm.	300	N.A.	N.A.	As above.
B.31	Mark I	Upper	Bomber	Two B	·50	650	N.A.	N.A.	As above.

Abbreviations

B = Browning gun.
H = Hispano gun.
VGO = Vickers gas operated gun.
NA = Not applicable or no reliable information available.

APPENDIX 6

AMMUNITION

Type and Size.	Application and Remarks
	Ammunition in use prior to 1939
·303-inch W Mark I .. ·303-inch W Mark IZ	Armour piercing. For attack of armour up to 9-mm. in normal use, or up to 4-mm. if armour within aircraft structure. Mark IZ had nitro-cellulose propellent instead of cordite.
·303-inch ball Mark VII	For general training purposes.
·303-inch incendiary B Mark IVZ.	Phosphorous filled incendiary for attack of balloons and aircraft. Nitro cellulose (N.C.) propellent.
·303-inch blank Mark VZ	Used in training and during ceremonial occasions to simulate firing of live rounds.
	Ammunition introduced during 1941
20-mm. H.E./I	Fuzed shell for attack of aircraft petrol tanks and structure possessed both high explosive and incendiary effect.
20-mm. A.P. Mark IZ ..	An interim 'monobloc' design usable only in steel ended magazine installations. Used for attack of armoured fighting vehicles (A.F.V.) from the air; also locomotives and lightly armoured transport.
20-mm. tracer Mark IZ ..	Long range tracer for air to ground and ground to air use. Not used in air to air fighting.
·303-inch G Mark IVZ ..	Day ranging tracer. Trace length 0-600 yards at 10,000 feet altitude.
·303-inch G Mark VZ ..	Night ranging tracer with similar characteristics to IVZ.
·303 inch incendiary B Mark VIZ	Used for attack of petrol tanks in aircraft. Superseded by B Mark VIIZ in 1942.
	Ammunition introduced during 1942
40-mm. practice Mark IA	For training purposes.
40-mm. A.P. Mark I ..	For attack of A.F.V.s. Propellent suitable for world-wide use.
40-mm. A.P. Mark II ..	For attack of A.F.V.s. Propellent charge greater than in the Mark I in order to obtain maximum armour penetration at lower temperatures. Suitable for use in temperate climates only.
20-mm. A.P. Mark IIZ ..	Armour piercing for attack of A.F.V.s, locomotives and lightly armoured transport. Could be used with all types of feed mechanism.
20-mm. S.A.P./I. Mark IZ	A non-fuzed incendiary shell with medium armour piercing performance. Designed for attack of petrol tanks protected by armour and heavy aircraft structure.
·5-inch incendiary B Mark IIZ.	British design used for attack of petrol tanks.
·303-inch incendiary B Mark VIIZ.	For attack of petrol tanks in aircraft; M.T. petrol tanks, etc.; was an improved design over B Mark VI which it superseded.
·303-inch tracer G Mark VIZ	Day ranging tracer, 0–600 yards. Had better ballistics than G Mark IVZ which it superseded.
	Ammunition introduced during 1943
40-mm. A.P. Mark V ..	For attack of A.F.V.s; had slightly better penetrative performance than Marks I and II; and was easier to produce.
40-mm. A.P. Mark VT ..	As for Mark V, but incorporated trace.
40-mm. practice Mark IV	For training purposes; had similar trajectory to A.P. Mark V.
40-mm. practice Mark IVT	For training purposes; had similar trajectory to A.P. Mark VT.
40-mm. A.P. Mark I* and II*.	Similar to Marks I and II armour piercing, but base plug in shot omitted as it occasionally broke up on firing.

Type and Size.	Application and Remarks.
Ammunition introduced during 1943—*continued*	
40-mm. S.A.P./H.E./I. ..	A base fuzed shell with medium armour piercing performance. Introduced as a general purpose shell.
20-mm. H.E./I Mark IIZ with fuze No. 253 Mark II	Similar to Mark IZ, but having a longer effective range owing to change in design of fuze.
20-mm. A.P. Mark IIIZ	A tungsten-carbide cored shot developed for attack of targets which were immune to attack by A.P. Marks I and II.
20-mm. H.E./I Mark IIZ with fuze No. 254 Mark IV	As for Mark IIZ but fitted with No. 254 Mark IV fuze.
·5-inch tracer G Mark IIIZ	British manufacture night ranging tracer. Trace 0–600 yards.
20-mm. A.P. Mark IVZ ..	A monobloc design, replacing A.P. Mark II because of easier production.
20-mm. A.P. tracer Mark IZ (day).	Primarily developed as a ranging tracer for air to air attack. Used on armour piercing body for maximum target effect.
20-mm. A.P. tracer Mark IZ (night).	Similar to A.P./T Mark IZ but incorporated trace suitable for night use.
20-mm. S.A.P./I Mark IZ (with detonator).	As for S.A.P. Mark IZ but incorporated a detonator to increase sensitivity.
·5-inch tracer G Mark VZ	Ball night ranging tracer. Improved design over Mark IIIZ which it superseded. Trace 0–600 yards.
Ammunition introduced during 1945	
·5-inch tracer G Mark IVZ	Ball day ranging tracer. Trace 0–1,000 yards.

American design ammunition used in the R.A.F.

Size and Type.	Date of Introduction.	Remarks.
20-mm. A.P. TM.75 ..	1942	Design similar to A.P. Mark IVZ with long range tracer filling. Never used in British installations owing to faulty gun functioning.
·5-inch A.P. Mark I ..	1941	Medium armour piercing performance. Little used.
·5-inch ball Mark I ..	1941	Training purposes.
·5-inch tracer AN–M10 ..	1945	Long range tracer for air use. Had dark ignition up to 300 yards, then bright trace to 1,600 yards.
·5-inch A.P./I AN–MB ..	1945	Combined armour piercing and incendiary properties.
·30-inch incendiary Mark I	1941	For attack of petrol tanks in aircraft and M.T.
·30-inch ball Mark I ..	1941	Training purposes.
·30-inch ball Mark II ..	1941	Improved design over Mark I.
·30-inch tracer Mark I ..	1942	Ball day tracer. Length of trace 0–1,000 yards.
·30-inch A.P. Mark II ..	1942	Penetration of light armour.

APPENDIX 7

ROCKET PROJECTILES USED IN THE ROYAL AIR FORCE 1939–1945

MOTORS

Nomenclature.	Weight (lb.)	Diameter (inches)	Length (inches)	Remarks.
Motor rocket aircraft, 3-inch No. 1 Mark I.	30·21	3·25	55·2	Tubular cordite charge.
Motor rocket aircraft, 3-inch No. 1 Mark II	28·5	3·25	55·2	Cruciform cordite charge.
Motor rocket aircraft, 3-inch No. 1 Mark III.	28·5	3·25	55·2	Cruciform cordite charge.
Motor rocket aircraft, 3-inch No. 1 Mark IV.	28·5	3·25	55·2	Special for tier carriage.

HEADS

Nomenclature.	Weight (lb.)	Diameter (inches)	Length (inches)	Remarks.
Shot A.P. 25 lb.	24·75	3·44	9·4	—
Shot S.A.P. 25 lb. ..	24·75	3·44	9·4	Mild steel.
Shell S.A.P. 60 lb. ..	60	5·98	19·72	—
Shot practice 25 lb. ..	25	5·0	11·6	Concrete.
Shot practice 60 lb. ..	60	6·0	21	Concrete.

APPENDIX 8

PYROTECHNICS

Date of Introduction.	Nomenclature.	Reason for Introduction.
1st Quarter 1941	Flame floats Mark II	To assist navigation at high altitudes over the sea.
	Smoke floats No. 1	Various Marks, for Fleet Air Arm navigation.
	Flares a/c landing wing tip Mark IV	Assisting night landings without floodlights.
	Generators smoke No. 15 Mark I	Signal from target motor boats.
	Smoke floats No. 3 Mark I ..	Fleet Air Arm dinghy distress signal.
	Flashes photographic 4·5-inch Mark I.	Replaced 8-inch flash for chute launching night photography.
	Flares 4-inch towed reconnaissance	For sea searching, later used as high speed target for training.
	Flares a/c reconnaissance 4-inch training Mark IV.	Originally reconnaissance training, later Marks adopted by Coastal and Fleet Air Arm for anti-submarine warfare.
	Markers sea alum. Mark V ..	Navigation aid over the sea.
2nd Quarter 1941	Signals light and sound 3-star red	Warning of enemy invasion.
	Signals 5-star green	As above.
	Flares a/c illuminator Mark I ..	Interception of enemy aircraft—never used for this, but adopted in anti-submarine warfare as alternative to Leigh Light.
	Flares a/c illuminator Mark II ..	As above.
	Flares a/c reconnaissance 4·5-inch Mark V.	Illumination for reconnaissance and bombing purposes, various Marks introduced with different delays for various types.
	Cartridge signal 1½-inch E.A. Types 1–6.	Imitation of enemy recognition signals.
	Fuzes No. 42 Mark II	Replaced No. 35 fuze on account of manufacturing difficulties. To burst clusters, flares, etc., above ground level.
3rd Quarter 1941	Fuzes No. 848 Mark I	Air armed version of 42 fuze to give added safety to aircraft.
	Fuzes destruction for 'M' balloons	Self-destroying fuze for leaflet balloons.
	Cartridge signal 1½-inch G.R. Types 16–33.	Recognition signals.
	Flame floats message carrying Mark I.	Air/sea rescue.
	Markers marine Mark I	Position marker—Anti-submarine.
	Fuzes No. 844 Mark I	For use in smoke float aircraft No. 2.
4th Quarter 1941	Simulators incendiary bomb Mark I smoke.	Training.
	Matches waterproof safety No. 1	To light failed signal distress marine.
1st Quarter 1942	Cartridges signal 1-inch red Mark XII.	Dinghy distress signal.
	Calibrators altimeter flash Mark I	Measuring height of aircraft.
	Cartridges signal 1½-inch C.A.F. Mark I (day).	As above.
	Cartridges signal 1½-inch C.A.F. Mark II (night).	As above.
	Flares emergency red Mark I ..	Flying control.
	Thunderflashes Lachrimatory Mark I.	Training.

Date of Intro-duction.	Nomenclature.	Reason for Introduction.
2nd Quarter 1942	Generators Smoke No. 6 Mark II (modified for Lindholme dinghy).	Distress signal.
	Signals distress 2-star red Mark I	Distress signal 'K' type dinghy.
3rd Quarter 1942	Cartridge Lux electric Mark I ..	Dinghy inflation.
	Cartridges signal 1½-inch double star green/green Mark IV.	Change of recognition signals continually required.
	Cartridges signal 1½-inch double star green/yellow Mark IV.	As above.
	Cartridges signal 1½-inch double star green/red Mark IV.	As above.
	Cartridges signal 1½-inch green Mark VI.	As above.
	Cartridges signal 1½-inch G.R. Type 21 Mark II.	As above.
	Cartridges signal 1½-inch G.R. Type 23 Mark II.	As above.
	Cartridges signal 1½-inch G.R. Type 26 Mark II.	As above.
	Cartridges signal 1½-inch G.R. Type 29 Mark II.	As above.
	Rockets kite launching Mark I ..	Air/sea rescue.
4th Quarter 1942	Generator smoke No. 18 Mark I..	Ground to air signal.
	Bombs M/L 2-inch mortar smoke	R.A.F. regiment.
	Bombs M/L 2-in. mortar illuminating.	As above.
	Bombs M/L 2-inch mortar signal red.	As above.
	Bombs M/L 2-inch mortar signal green.	As above.
1st Quarter 1943	Rockets bouyant line carrying No. 1 Mark I.	Fitted to airborne lifeboat.
	Rockets illuminating 9-lb. Mark I	Snowflake rocket for illumination of convoys and later used as flying bomb warning.
2nd Quarter 1943	Signals drift night A.N. Mark IV	Navigation aid.
	Markers marine Mark III ..	Position marker for anti-submarine reinforcing sorties with armed clockwork delay.
4th Quarter 1943	Cluster a/c projectile No. 2 ..	To cluster several flares for carriage on bomb stowage.
	Rockets illuminating 9 lb. Mark II	Flying bomb warning signal.
1st Quarter 1944	Rockets illuminating 3¾-lb. No. 2 Mark I.	Hand fired rocket for air/sea rescue launches.
	Rockets illuminating 6¼-lb. No. 1 Mark I.	Flying bomb warning—in conditions of low cloud.
	Cartridges photographic flash 1½-inch Nos. 1–8.	Low altitude night photography.
	Grenades hand No. 80 Mark I W.P.	R.A.F. Regiment.

Date of Intro-duction.	Nomenclature.	Reason for Introduction.
2nd Quarter 1944	Flame floats No. 3 Mark II ..	Fleet Air Arm distress signal.
	Cartridges signal 1½-inch double star green/red Mark V.	Continual need to change recognition signals.
	Cartridges signal 1½-inch double star green/yellow Mark V.	As above.
	Cartridges signal 1½-inch double star red/red Mark III.	As above.
	Cartridges signal 1½-inch double star red/yellow Mark III.	As above.
	Flashes photograph Mark III ..	Safer filling than the Mark II.
	Bombs a/c nickel No. 1 Mark I ..	Leaflet bomb for propaganda.
3rd Quarter 1944	Rockets warning 9-lb. Mark I red	Warning to fighter pilots when entering undefended areas.
	Cartridge electric rocket 1-inch Mark II.	For airborne lifeboat.
	Bombs a/c nickel No. 2 Mark I ..	Leaflet bomb for propaganda.
	Bombs a/c nickel No. 2 Mark II ..	As above.
	Indicators flame a/c sea rescue No. 1 Mark I.	Air/sea rescue.
	Rockets target practice 1-lb. Mark II.	Training A.A. gunners against dive bombers.
4th Quarter 1944	Fuzes No. 848 Mark VII	For P.F.F.
	Bombs a/c nickel No. 3 Mark I ..	Munro leaflet bomb for propaganda.
1st Quarter 1945	Flares ground indicating No. 1 Mark I.	Ground to air signal flying control.
	Flares a/c reconnaissance 4·5-inch No. 4 Mark I white.	P.F.F.
	Fuzes No. 889 Mark I	Improved initiator for marker marine.
2nd Quarter 1945	Flashes photographic 4·5-inch Mark IV.	Safer bursts and more illumination than Mark III.

APPENDIX 9

TABLE SHOWING DETAILS AND CHARACTERISTICS OF 250 LB. TARGET INDICATOR (T.I.) BOMBS

Serial No. of Bomb.	Details of Contents.	Characteristics.
1	60 non-delay candles (red, green, yellow or white, as ordered).	A cascade of 60 candles which continue to burn on the target with a total time of burning of approximately three minutes for red, green and yellow and approximately five minutes for the white.
2	56 non-delay and four explosive candles (red, green, yellow or white as ordered).	Similar to No. 1, giving three series of explosions at intervals.
3	20 non-delay and 40 delay candles (red, green or yellow as ordered).	A cascade of 20 candles on striking the target. Approximately one third of the candles burn at a time, giving a total time of burning of approximately seven minutes.
4	16 non-delay, 40 delay and 4 explosive candles (red, green or yellow as ordered).	Similar to No. 3, giving two series of explosions at intervals.
5	30 non-delay and 30 delay candles (red, green or yellow).	A cascade of 30 candles on striking the target. A diminishing percentage of candles burn at a time, giving total burning time of approximately seven minutes.
6	26 non-delay, 30 delay and 4 explosive candles (red, green or yellow).	Similar to No. 5, giving two series of explosions at intervals.
7	210 flash units, each unit containing a delay fuze (red or green).	A succession of flashes at intervals of approximately 1·5 seconds, duration of each flash one tenth of a second. Total time of functioning approximately five minutes.
8	Cotton bale saturated in solution of metallic perchlorate dissolved in alcohol (red, green or yellow).	A single spot of colour on the ground with a total burning time of 15 to 20 minutes.
9	60 delay candles (red, green or yellow).	No cascade. All candles function 2½ minutes after ejection. Total burning time approximately two minutes.
10	60 delay candles (red, green or yellow).	Similar to No. 9 but candles function five minutes after ejection.
11	One 4·5-inch photo-flash plus concrete rings for weighting.	Ejects photo-flash unit which ignites after a delay of two seconds.
12	One 4·5-inch photo-flash and 40 delay candles (candles red, green or yellow).	Ejects photo-flash unit and candles. No cascade. Photo-flash ignites after delay of two seconds. Candles ignite after a delay of approximately 2½ minutes and burn for approximately two minutes.
13	One 4·5-inch photo-flash and 40 non-delay candles (candles red, green or yellow).	Ejects photo-flash unit and candles. Photo-flash ignites after delay of two seconds. Gives a cascade of 40 candles, which continue to burn on the target with a total burning time of approximately three minutes.
14	27 candles, each with a parachute (red, green or yellow).	Ejects candles. Candles suspended in a bunch. Total time of burning approximately three minutes.
15	30 non-delay and 30 explosive candles (red, green or yellow).	Gives a cascade of 60 candles, which continue to burn on the target with a burning time of approximately three minutes. Three series of explosions at intervals.
16	11 non-delay, 45 delay and 4 explosive candles (red green or yellow).	Gives a cascade of 15 candles on striking the target. A percentage of the candles burn at a time giving a total time of burning of approximately 12 minutes. Four explosions at intervals.

Serial No. of Bomb.	Details of Contents.	Characteristics.
17	60 non-delay candles, each with alternative coloured increments (red/green, red/yellow or yellow/green).	A cascade of 60 candles in first colour. After approximately 30 seconds colour changes and alternates every 15 seconds. Total time of burning approximately three minutes.
18	24 non-delay and 3 explosive candles each with alternate coloured increments(red/green,red/yellow or yellow/green).	A cascade of 27 candles in first colour. After approximately 30 seconds, colour changes and alternates every 15 seconds. Total time of burning approximately 5½ minutes. Three explosions at intervals.
19	Perforated container of sodium phosphide and phosphorus.	Container is ejected and ignited and produces a yellow flame on striking water. Total time of burning eight to ten minutes.
20	Smoke composition and concrete rings for weighting.	On fuze functioning, bomb disintegrates and gives a puff of smoke in sky. Not for operational use.
21	210 flash units, each containing a delay fuze (red, green or yellow).	A succession of flashes at intervals of approximately 1·5 seconds. Duration of each flash approximately four seconds. Total time of functioning approximately five minutes.
23	Nine non-delay and 39 delay candles in 16 bundles of three (red, green or yellow).	A cascade of nine candles (three bundles) on striking target, two or three of the bundles burn at a time, giving a total time of burning of approximately 12 minutes.
24	Eight non-delay, 48 delay and four explosive candles (red, green or yellow).	A cascade of 60 candles on striking the target. A percentage of the candles burn at a time, giving a total time of burning of approximately 12 minutes. Four explosions at intervals.
25	Four non-delay, 34 delay candles (red, green or yellow).	A cascade of four candles on striking the target. A percentage of the candles burn at a time, giving a total time of burning of approximately 20 minutes.
26	11 non-delay, 45 delay and four explosive candles (red, green or yellow).	A cascade of 31 candles on striking the target. A percentage of the candles burn at a time, giving a total time of burning of approximately 12 minutes. Four explosions at intervals.
27	One non-delay, 31 delay units ..	One unit functions in the air, and the remainder on the ground giving a series of short and long flashes representing morse letters, repeated at intervals of approximately 20 seconds over a period of approximately 24 minutes.
28	16 non-delay, 40 delay and four explosive candles (red, green or yellow).	A cascade of 60 candles on striking the target. Approximately one third of the candles burn at a time giving a total time of burning of approximately 6½ minutes. Four explosions at intervals.
29	Pigment, colour as ordered (red, yellow, green or blue).	A coloured puff in the sky.
30	60 yellow, green or blue smoke non-delay candles or 16 non-delay red smoke, and 16 delay red smoke candles.	A cascade of 60 candles which gives an emission of coloured smoke for approximately three minutes, or gives a cascade of 16 candles on striking the target. Approximately half the candles burn at a time to give a total time of burning of six minutes.