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THE SECOND WORLD WAR
1939–1945
ROYAL AIR FORCE

ARMAMENT

VOLUME I

BOMBS AND BOMBING EQUIPMENT

Promulgated for information and guidance of all concerned.
By Command of the Air Council,

J. H. Barnes.

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BOMBS AND BOMBING EQUIPMENT

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PART I

BOMBS

INTRODUCTION

Prior to the fusion of the Army and Naval Air Services in 1918, development of aerial missiles had proceeded independently in the War Office and the Admiralty. In consequence progress was of a miscellaneous nature and, when the war ended, development in bomb design was mainly centred around the evolution of an outline to give maximum ballistic efficiency consistent with the maximum filling capacity, simplification and standardisation for manufacture, and the introduction and simplification of fuzing methods.

During the between-war years proposals were made for the development of a wide range of High Explosive and Incendiary bombs up to 4,000 lb. weight suitable for use against land targets. The prevailing condition, however, dictated a policy in which weapon efficiency was second to aircraft design ; this, and the restricted amount of money available for research and development, caused the proposals to be drastically curtailed and was largely responsible for the state of affairs in which we found ourselves in 1939.

At the outbreak of the Second World War, aircraft bombs were essentially little different from those used by the Royal Flying Corps in 1918, the largest bomb available for use against land targets was the 500 lb. General Purpose, the type of high explosive filling in use was the same as used in aircraft high explosive bombs during the First World War, and no Royal Air Force aircraft existed which, without modification, could carry a bomb of greater weight than 2,000 lb.

This position was no reflection on those responsible for armament design, but the fruits of a policy dictated by circumstances in which active warfare was only considered a remote possibility.

This narrative outlines briefly the various types of bombs evolved during the years of peace and the main developments during the Second World War. For convenience and to avoid confusion, the bomb series and certain special bombs are dealt with separately, but the reader is advised to remember that together they form a complete picture and part of the structure upon which total victory was finally achieved.

Mines and Torpedoes, although used by the Royal Air Force during the Second World War, have not been mentioned in this narrative as they were primarily a Naval requirement, being developed by the Royal Navy and maintained by Naval personnel.

CHAPTER 1

GENERAL PURPOSE AND FRAGMENTATION BOMBS

Early history

After the 1914–1918 War the Royal Air Force was left with stocks of aircraft bombs which were a mixed collection of shapes and sizes with many different methods of construction and fuzing. Between 1921 and 1922 considerable discussion took place between the Air Staff and the various departments connected with armament research and development as to the formulation of policy regarding bombs and the trend of future developments.

Included in the development programme approved by the Air Staff in April 1922 was the General Purpose (G.P.) series. Such a range of bombs (provisionally 50 lb., 250 lb. and 500 lb.) would help to standardise type and shape, simplify design and manufacture, and have a reasonable efficiency against all types of unarmoured or lightly protected targets. No mention of performance requirements was made in these early deliberations, matters being confined to the policy of types of bombs and weights, and consideration of size in relation to contemporary aircraft.

Authority to proceed with research and design was given by the Chief of Air Staff to the Director General of Supply and Research (D.G.S.R.) in April 1922, and a start was made to find the best external contour.[1] After investigations lasting until October 1923, which included wind tunnel tests at the Royal Aircraft Establishment (R.A.E.), the shape of the new bombs was settled and in the following December the Design Department, Woolwich, was asked to prepare designs accordingly.[2]

Design and trials of G.P. bombs

Early in January 1924 an Air Staff requirement was stated for a 120 lb. bomb, to give a greater variety of bomb load and, as suggested by the Deputy Chief of Air Staff (D.C.A.S.), to avoid the necessity of carrying a 250 lb. bomb because one of 50 lb. would not do sufficient damage. There were thus four bomb sizes required, the Ordnance Committee being so informed in January 1924, with the request that the Committee would impress on all departments concerned the urgent necessity of completing the designs as soon as possible.[3] By May 1924 the designs had been completed and six bombs of each size were being manufactured at Woolwich Arsenal, all having central tubes (although it had been hoped this might be avoided). Actually, design had gone ahead before theoretical experiments with new methods of fuzing and detonation had been completed.

For a bomb which could be described as 'General Purpose' an explosive content of approximately 30 per cent. was hoped for. In practice this was not achieved, the capacity varying from about 23 per cent. to 25 per cent. when the

[1] A.M. File S. 17413.
[2] A.M. File S. 23218.
[3] A.M. File S. 19080. For a detailed account of the procedure governing armament design and development, *see* Appendix No. 1.

designs were worked out by the Design Department at Woolwich. The minimum case thickness in the 500 lb. size was 0·75 inch, and for the first time in H.E. bombs the tail unit consisted of a steel cylinder attached to the bomb body by steel supports to give better ballistic stability.

A number of difficulties were met with in this early experimental production, but by 1925 sufficient inert filled bombs of 250 lb. and 500 lb. were ready for grouping trials to test ballistics. In air dropping trials at Orfordness (June/July 1925) with old type bombs of similar weight, the new shaped bombs showed high promise; in every instance there was more consistent trajectory and stability in flight. For example, from 10,000 feet the ground dispersal spacing of salvoes of G.P. bombs was from 5–20 yards, while for the old type bombs it was as high as 150 yards.[1]

Although much research remained to be done the Air Member for Supply and Research (A.M.S.R.) strongly recommended that the designs be approved as they then stood. Considerable anxiety was felt about the low state of bomb stocks generally, and A.M.S.R., in his recommendations to the Air Staff, considered it imperative that some bombs of the new type should be produced. They were undoubtedly an improvement on the old bombs; subject to many hoped for improvements, they were stepping stones to standardising at least one series of bombs; the general shape and size would remain the same and it was thought essential that the Service should acquire experience of the new type. After considerable discussion it was agreed by C.A.S., in July 1925, that the 120 lb., 250 lb. and 500 lb. bombs should be produced for service use to bring bomb stocks up to six months war reserve; the 50lb. bomb was to be redesigned.[2]

Thus the first G.P. bombs, the Mark I series, began to take shape, the charge/weight ratio was estimated to average about 23 per cent., the filling was to be 80/20 Amatol. The Design Department immediately began to overhaul the designs in consultation with Air Ministry with the object of making as many improvements as possible before advancing to a Mark II series. The improvements sought were mainly concerned with increasing the charge/weight ratio and ease of manufacture for bulk production.[3]

Meanwhile, as a result of suggestions by D.C.A.S. in November 1924, it was thought advisable to go ahead with designs of larger bombs (1,000 lb.–4,000 lb.) in anticipation of the production of aircraft capable of carrying them, and Air Staff approval was given for the design and development of such bombs. It should be mentioned at this stage that some years later work on the bombs above 500 lb. in weight was temporarily abandoned, but for the time being this account will deal with the whole range 50 lb.–4,000 lb.

Development 1926–1932

By May 1926, model bombs based on the proposed designs for the larger bombs had been dropped and much useful data obtained; further similar trials were to be held. Regarding the smaller series, experimental orders had been placed with three trade firms to obtain further experience in manufacturing

[1] A.M. File S. 23218. These early ballistic trials were crude and unsatisfactory; it was not until 1928 that a scientifically designed range was established at Orfordness and the characteristics of the new bombs accurately recorded.

[2] A.M. File S. 47814/24.

[3] A.M. File S. 23218.

problems; fragmentation trials had been arranged as also had firing trials (500 lb. bombs adapted for firing from a howitzer) to test penetration and resistance to impact with hard targets.[1]

In December 1926, following the conclusion of model ballistic trials, a sketch design for the 1,000 lb. bomb was prepared in the Air Ministry and sent to the Design Department, Woolwich, for the latter to prepare a suitable design for experimental production. The outline was prepared from a scaled up 500 lb. bomb, with an estimated charge/weight ratio of 32 per cent. for a filling of 80/20 Amatol.[2]

The four-floor penetration target was completed by the end of 1926 and the first firing trial took place in January 1927 with two main objects in view :—

(*a*) To ascertain the penetration of a 500 lb. G.P. bomb against a target representative of a building as might be used for Government office or a factory.

(*b*) To ascertain whether the design was sufficiently robust to be in a fit state for detonation when fuzed for delay action.

The trial was not successful as the bomb unfortunately broke up shortly after leaving the gun, but the nose portion—about three-quarters of the bomb—passed through all the 'floors'. Although inconclusive, this trial at least indicated the improbability of such a target resisting a bomb of such type and weight; a feature of interest to Home Office A.R.P. representatives who had attended the trial. The break-up of the bomb was discussed with the Ordnance Committee and it was decided that, in future trials, an attempt should be made to give the bomb the required striking velocity (S.V.) with a lower chamber pressure.[3]

By July 1927, fragmentation trials of the smaller series (50 lb.—500 lb.) had been satisfactorily completed, and the design for the 1,000 lb. bomb had been approved for experimental production. Such bombs were to be tested in trials similar to that already outlined for the smaller series.[4] It may be noted that so far the only reference to larger G.P. bombs has concerned the 1,000 lb. size. This was because, very wisely, the development programme was based on successful production of that size in parallel with the 500 lb. bomb; design of other bombs up to 4,000 lb. would follow the same lines if the 1,000 lb. type was successful. Actually, by the end of 1927, the Air Staff had decided that only the 1,000 lb. and 2,000 lb. sizes were for the time being to be developed, the latter in any case to await successful trials of the former.[5]

In 1928 two more concrete targets, similar to the original, except that they had six 'floors' instead of four, were constructed at Shoeburyness. In one case the floors were tilted back at an angle of 10 degrees to the vertical; in the other target the angle was 20 degrees to represent an angle of impact from dropping heights of 10,000 feet and 2,000 feet respectively. By May of that year, some of the first experimental 1,000 lb. bombs were completed and two months later two bombs were fired for recovery from an 18-inch howitzer at

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[1] A.M. Files S. 23218 and S. 25514. A target representing four floors of reinforced concrete building was being constructed at Shoeburyness.

[2] A.M. File S. 24734.

[3] A.M. File 678808/26.

[4] A.M. Files 678808/26 and S. 24734. The method of detonation and fragmentation trials at that time was underwater by electric firing.

[5] A.M. File S. 17413.

Shoeburyness.[1] This trial was successful, trajectory was very stable and the bombs were undamaged; the velocity represented a drop from 13,400 feet, and it was decided that firing trials against the new type concrete targets would be held after similar trials with the smaller G.P. bombs had been completed.[2]

The new concrete targets were used in October 1928 when 120 lb. and 500 lb. bombs were again fired from a gun for penetration tests. In two cases bombs struck heavy wooden floor supports with resultant deflection but the trial was sufficiently conclusive to prove the following points :—

(*a*) The resistance offered by the actual concrete was low and in fact proved that the 'floors' themselves would not damage the bombs.

(*b*) The 250 lb. and 500 lb. bombs would penetrate any number of floors likely to be encountered, provided they did not meet heavy floor supports. A 500 lb. bomb had been badly damaged from impact with a wooden strut; this required investigation as impact with a steel support would cause more severe damage.

The most important decision resulting from this trial was that a similar test would be carried out against a steel girder target, and that any decision regarding modification of the construction of G.P. bombs would depend on the results of such a trial.[3]

Consideration of alternative H.E. filling

For a number of reasons there was considerable discussion between Air Ministry Research Department, Woolwich and the Ordnance Committee in 1929 on the possibility of using a filling other than the standard Amatol. As previously mentioned, a quantity of G.P. bombs (120 lb.–500 lb.) was being produced to restore Royal Air Force stocks to a reasonable war reserve and the Amatol filling was far from satisfactory for long storage.[4] The alternative chosen for experiment was Baratol, normally used in the proportion 10/90—Barium Nitrate/T.N.T., but it was hoped to increase the percentage of the former. This might well improve the detonation performance and, because of supply limitations of T.N.T., would in any case be a necessity. The Research Department decided to experiment first with the proportions 30/70, 50/50 and 70/30, and it was arranged to fill some 250 lb. bombs for comparison with 80/20 Amatol.[5]

In June 1929 Air Ministry decided on the recommendation of the Ordnance Committee that no further contracts should be placed in peacetime for Amatol filling because of the corrosive action. It was however realised that supply questions in a major war, might necessitate a reversal of that policy and arrangements were made to improve the protection of bomb bodies against Amatol by various types of varnishing.[6]

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[1] 'Fired for recovery'—an artillery term for a method which when it is required to measure the velocity and ascertain what damage, if any, the projectile has sustained in being fired. In this case it meant firing into the sea at high water and then recovery for inspection at low water.

[2] O.C. Memo. B. 16396.

[3] A.M. File S. 23218.

[4] 80 per cent. Ammonium nitrate, 20 per cent. T.N.T., the large proportion of the former set up corrosive action during prolonged storage.

[5] O.C. Memo. B. 18221.

[6] O.C. Memo. B. 18378.

Bomb case construction

Throughout 1929 and 1930, investigations had been held between Air Ministry Design Department and Chief Superintendent of Ordnance Factories (C.S.O.F.) into the possibility of using a better type of steel in casting G.P. bomb cases without an appreciable rise in cost. This partly arose from examination of the bombs previously used against the concrete targets.

It was hoped, for example, to improve the elongation figure for the steel by some simple heat treatment.[1] However, despite the most exhaustive tests this was found to be impracticable and it was finally recommended by the Chief Superintendent of Ordnance Factories that, with the adverse conditions encountered in casting, and the necessity for G.P. bombs to be capable of production in large numbers in almost any steel foundry in the country, an elongation requirement of 10 per cent. was the maximum that should be imposed. To aim higher than this would cause too many rejections, or alternatively would create considerable difficulties of special heat treatment and a consequent reduction of the number of foundries able to produce bomb bodies. The final recommendation therefore, was that a tensile breaking strength of 35 tons per square inch and 10 per cent. elongation would be reasonable figures to specify.[2]

By April 1932, the long series of trials, arranged some years before to investigate three main aspects in the design of G.P. bombs, had been completed. Briefly such trials had covered the following main points :—

(*a*) The effect of case strength on the detonating efficiency of bombs identical in shape.

(*b*) The comparative efficiency of various H.E. fillings in bombs of identical shape and strength.

(*c*) The effect of shape on the dispersion of fragments from bombs of equal strength and charge weight.

The results indicated, with regard to (*a*) that lower grade steels gave the highest pressure blast velocity and fragment velocity. On the other hand the penetration effect of fragments of better quality steel was better than that of lower grade steel at the same striking velocity.

Regarding (*b*), the highest blast velocity and pressure was given by T.N.T. In addition, the average fragment weight in T.N.T. filled bombs was lower, indicating a more complete break up of the body than was obtained with either Amatol or Hexanite.[3] The results obtained in (*c*) provided insufficient evidence as to the effect of shape on the variation in distribution and density of fragments.[4]

It is necessary at this stage to refer again to the H.E. filling for G.P. bombs, it may be remembered that in 1929 it was decided that after the initial production orders for Mark I bombs had been completed no more bombs would be filled 80/20 Amatol.

In July 1931 that decision was reversed for although experiments showed a Baratol mixture 70/30 to be far superior in performance, the equivalent amount of that explosive would increase the weight of a 250 lb. bomb by 44 lb. Thus it

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[1] 'Elongation '—in a tensile test of steel the increase in length of a test piece at the moment of fracture.

[2] O.C. Memo. B. 21574.

[3] A composite explosive experimented with at that time.

[4] O.C. Memo. B. 24273.

was agreed that pending a re-design to accommodate such a filling—or that of pure T.N.T.—with due allowance for the increase in weight over Amatol, the latter filling could be used provided an effective anti-corrosive was applied. This decision gave rise to series of long discussions between the Research and Development Staff of Air Ministry and Air Staff on the future policy regarding bomb development. With so much research yet to be completed it was felt by A.M.S.R.'s staff that a revision of policy regarding bomb types was necessary in order to avoid complication in design work and multiplicity of types. After discussions lasting from June 1931 until July 1932, the Air Staff decided that, for the time being, only three sizes of G.P. bombs, 120 lb., 250 lb. and 500 lb., were required.[1] One of the reasons for the abandonment of the 1,000 lb. size was to assist aircraft design. Thus after about seven years careful and thorough work, when the design had passed all tests except that of live dropping, the production of the larger bombs was shelved.

The 20 lb. (F) bomb

Among the bomb stocks held by the Royal Air Force after the First World War was a large quantity of 20 lb. anti-personnel bombs. These, known for some years as 'Cooper' bombs, after the designer, had proved quite successful except for some uncertainty of action from very low altitudes. Compared with the larger bombs it was, for several years, thought unnecessary to experiment with new designs for this type which was re-named Bomb H.E. Aircraft 20 lb. Mark I.

In 1929 the American periodical 'Army Ordnance' contained particulars of a new anti-personnel bomb weighing about 26 lb. The body was made of steel rings assembled over a steel tube, the rings being held in place by nose and tail castings. It was stated that after detonation the bomb broke up into some 1,400 fragments of an average weight of 0·27 oz. These particulars were of great interest to the Armament Research Staff at Air Ministry. If correct it meant that 22–23 lb. of lethal fragments must have been recovered, whereas an ordinary cast steel bomb weighing approximately 19 lb. provided only about 500 fragments of 0·15 oz., a total of nearly 5 lb.[2]

As further orders for the 20 lb. bomb would at some time be required, and any improvement in design was desirable the Assistant Director of Armament Research and Development (A.D.R.D. Arm.) discussed the claims for the 'ringed' bomb with the Chief Superintendent, Research Department (C.S.R.D.) who advised that the method of construction merited investigation.

Therefore, as a normal technical investigation as compared with an Air Staff requirement, it was decided in June 1929 to design some experimental 'ringed' bombs for comparative fragmentation trials with other bombs—also to new design—of similar volume shape and case thickness, but made in one piece.[3] These trials were eventually completed at Shoeburyness in July 1930 and showed, as was expected, that the fragmentation of the ringed bombs was smaller than that of the corresponding one-piece bombs. In penetrative power against wooden targets the new type bomb fragments were also superior, but against steel plates upwards of ¼ inch thick the one-piece bombs showed a slight

[1] A.M. File S. 17413.
[2] A.M. File S. 29822.
[3] A.M. File S. 17413 and O.C. Memo. B. 19471.

superiority. The opinion of C.S.R.D. and the Ordnance Committee was that the investigation warranted further research and arrangements were made accordingly.[1]

Whilst preparations for the next series of trials were in hand, it was agreed by Air Ministry and the Ordnance Committee, in September 1931, to include the following variations of the American type bomb :—

(*a*) A closely wound continuous coil of square section wire ; this for the purpose of reducing cost and not to improve efficiency.

(*b*) Similar rings with three longitudinal external ' V ' cuts.

It was also decided to include some Service 20 lb. Mark I bombs so as to get a direct comparison.[2]

A long series of trials similar to the original, and including later the extra types of construction, was carried out between November 1931 and July 1933, and analysis of the results showed the following main points :—[3]

(*a*) A greatly diminished all-round effect of fragmentation at low heights of drop due to the oblique angle of the bomb. The curved contour bomb had a wider angle of fragment dispersion than that of the parallel-sided bomb and was thus more suitable generally for anti-personnel purposes. The service 20 lb. bomb was of the right contour but the trials indicated that more than 30 per cent. of its weight was ineffective owing to over-fragmentation.

(*b*) The advantage of the ' ringed ' bomb in actual fragmentation effect was most pronounced and it was considered that an effort should be made to combine that type of construction with a curved shape.

The general requirements for 20 lb. anti-personnel bombs were discussed at a meeting at the Ordnance Committee Office in March 1934, when it was decided to try and improve the existing bombs by substitution of a Baratol filling, and to design another solid-case experimental bomb for comparative trials.[4] At this meeting the ring-type bomb-body was rejected owing to the difficulty of construction in a streamlined form.

Trials commenced in September 1934 and went on intermittently until May 1936 when the design for the new bomb was settled on. A better quality steel was to be used, filling to be T.N.T. with a charge/weight ratio of 20 per cent. A suspension lug was required for carriage on Light Series carriers although it was anticipated that the bombs would normally be carried in the new container (the Small Bomb Container) then being designed.[5]

In December 1936, the new series was officially named the 20 lb. (F) Bomb, and small production orders for the Service were placed early in 1937. It was not until April 1938 that air dropping trials were held, with unsatisfactory results. Craters were excessively deep and fragmentation poor, and after careful research this was attributed to inefficient functioning of the nose pistol/detonator initiation. By the end of 1938, the use of sharp striker pistols and sensitive detonators had produced much better results and production of the new type (F) bomb was increased.[6]

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[1] O.C. Memo B. 21679.
[2] O.C. Memo. B. 23357.
[3] O.C. Memos. B. 25098, B. 25548 and B. 26799.
[4] A.M. File S. 29822. Apart from over-fragmentation the Amatol filling gave trouble in storage.
[5] A.M. File S. 29822.
[6] A.M. File S. 38384. *See* Chapter 15 on the development of sharp striker pistols and sensitive detonators.

Development 1933–1940

During the first two years of this period little of interest occurred in the development of the G.P. series. Air Staff policy still only required the three sizes 120 lb., 250 lb. and 500 lb. and, apart from minor technical modifications, these bombs remained as originally designed. In 1935, a Bomb Sub-Committee of representatives from the Air Ministry, Admiralty and War Office was set up. Its terms of reference included an investigation as to whether the necessary bombs and components existed for efficient attack of every type of target from the air, and if not to recommend remedial measures. The Committee first met on 20 May 1935, and its recommendations included the following :—

(*a*) A new 20 lb. bomb for carriage in small bomb containers.[1]

(*b*) A G.P. bomb of 30–50 lb. for use against M.T., houses and billets, aircraft on ground and similar targets.

(*c*) No effective or economical use could be found for the 120 lb. bomb and it was considered it should be abandoned.

These recommendations were considered by the Air Staff in September 1935 when agreement was given to all three proposals ; development of the 30–50 lb. bomb to have priority.[2]

In April 1936, trials were concluded with two major modifications to G.P. bombs as follows :—

(*a*) The use of snap-on tail units instead of the normal type which were screwed on. Attachment was made by the engagement of four spring clips on the tail unit with grooves on the bomb body.

(*b*) Built in exploder units in nose and tail, requiring only a pistol and detonator to complete the fuzing components.

These modifications were included in the Mark IV series of G.P. bombs and the designs were approved in September 1936.[3]

In November 1936, the design for the empty 40 lb. bomb was approved, and it followed closely that of the (F) bomb. The case was of steel—cast and forged—the filling to be 80/20 amatol with a charge/weight ratio of approximately 30 per cent. A built-in exploder system was designed and the non-sensitive fuzing was expected to be used for either instantaneous or 1/40th second delay action, according to operational requirements. The approximate weight, fuzed, was 38 lb. and it was therefore named the 40 lb. G.P. bomb.[4]

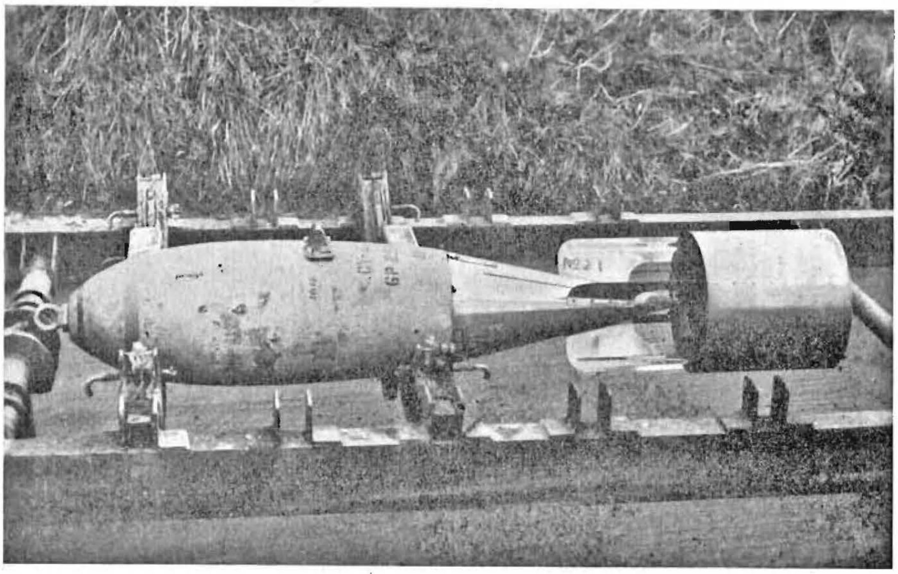
The method of filling was approved in May 1937, by which time it had been decided that the bombs would be made from forged steel only. Several private firms received small production orders during 1937 and 1938, and it was also decided to dispense with the suspension lug ; carriage was to be in Small Bomb Containers only.

Live bomb trials. 40 lb., 250 lb., Mark IV and 500 lb., Mark IV

The first air-dropping trials of live Mark IV bombs (250 lb.), were successfully completed at Martlesham Heath in April 1938, ballistics and detonation being satisfactory.[5] In the following month some live 40 lb. bombs were tested from

[1] Eventually the 20 lb. (F) bomb.
[2] A.M. File S. 17413.
[3] A.M. File S. 49133/36.
[4] A.M. File S. 38383.
[5] Martlesham Heath Report M/Arm/529/2 in A.M. File 549133/36.

1,600 feet as a preliminary to a demonstration intended to be given to the Air Staff. In common with the 20 lb. bomb trials, ballistics and detonation were good but fragmentation was poor. Bomb craters were excessively deep and the detonators were suspected.[1]



250 LB. G.P. BOMB MARK IV

Further trials were held up while investigations into the new pistol/detonator fuzing were in progress, but in October 1938 an important ballistic trial was completed at Martlesham Heath, to test single and salvo release.[2] The results showed that whilst bomb behaviour was generally good in single release, there was jostling after salvo release. This disappeared after about 100 feet of fall, but it had its effect in the ground dispersions of the bombs. An example of the haphazard dispersal is, that from 5,000 feet at an air speed of 300 feet per second (f.p.s.), a salvo of six bombs might vary between areas of 20 × 40 feet and 500 × 100 feet.[3]

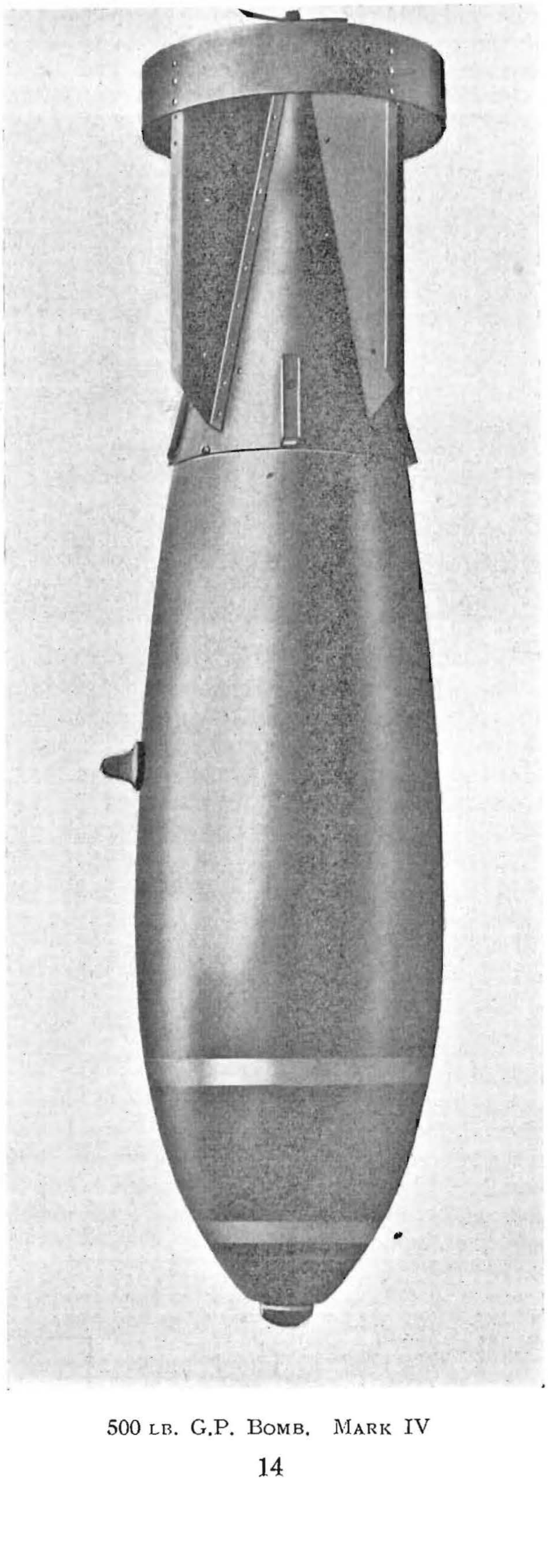
Comparative fragmentation trials were resumed at Martlesham Heath and Manby in December 1938 when the combination of sharp pistol striker and sensitive detonator gave a much better performance. In the following month Air Staff approval was given to the substitution of that form of fuzing, and, except for minor details the development of the 40 lb. G.P. bomb was concluded.

To return to the air trials of the larger bombs, a novel test was carried out at Martlesham Heath in June 1938. To test particularly the latest type of snap-on tail unit a number of 250 lb. and 500 lb. Mark IV bombs were released at 13,000 feet from the internal stowage of a Harrow aircraft with the bomb doors closed. The doors had therefore to be opened by the bombs on release, but despite this, and the effects of slip-stream, the bombs behaved well in flight, thus proving the efficiency of the tail-units.

[1] A.M. File S. 38383.

[2] Although the majority of 40 lb. bombs were made without suspension lugs for S.B.C. carriage—those for Fleet Air Arm use were provided with a lug for carrier release, hence the single release trials.

[3] A.M. File S. 38383/2. Salvo release was later improved considerably by alteration to the container.



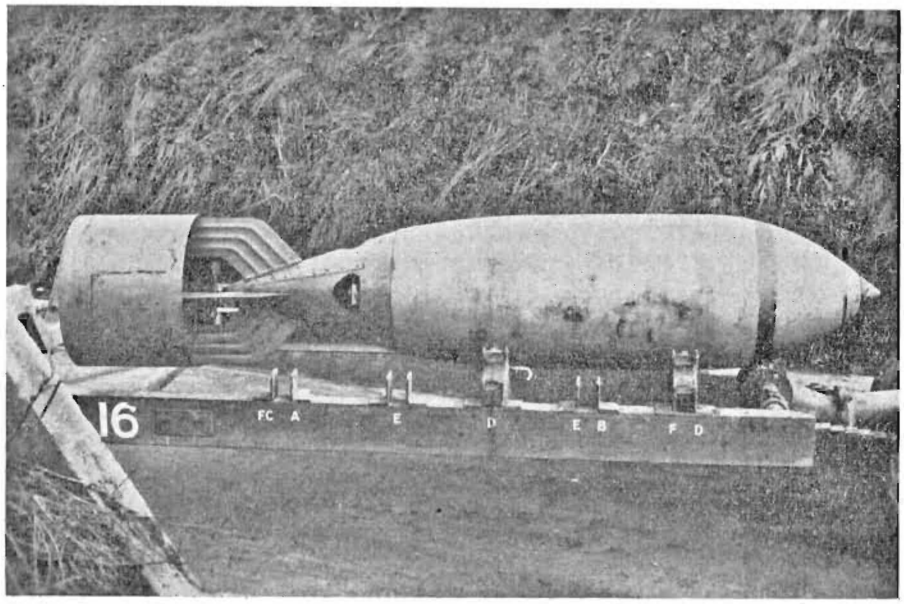
500 lb. G.P. Bomb. Mark IV

Similar trials from 20,000 feet, with one of the four securing clips removed, were carried out in the following month with equally good results. There had been some doubt whether these tail-clips would effectively engage with Mark IV bomb bodies, or that mishandling in ground preparation might break one off. These successful trials proved that even under such conditions the tail unit remained attached, and the bomb flight path was unaffected.[1]

Except for a trial in June 1940 which established that the minimum height from which G.P. bombs would function (direct action) on water was 1,100 feet, this ends the account of the 250 lb. and 500 lb. series.[2] Comment on their operational use and effectiveness in the Second World War will be reserved until later in this chapter.

The revival of the 1,000 lb. and larger bombs

In June 1938 the Operational Requirements (O.R.) branch of the Air Staff was preparing a paper for discussions by the Bombing Committee on the question of the re-introduction of bombs of 1,000 lb. and over.[3] For some months the Committee had been studying the problem of air attack on such targets as dams, railway bridges, overhead aqueducts and canals for the destruction of which the 500 lb. bombs might not be sufficiently powerful.[4]



1,000 LB. G.P. BOMB MARK III or IV

Whilst data was being collected as to stowage and carriage problems in the bomber aircraft then being prepared, as well as numerous other technical details required, the A.O.C.-in-C., Bomber Command put forward his views on the provision of 1,000 lb. bombs. He advocated in the strongest possible terms the

[1] Martlesham Heath Reports (M/Arm/529/3) (M/Arm/529/4) in A.M. File 782851/38.
[2] A.M. File 782851/38.
[3] An Air Ministry Committee representing the operational and technical staffs and the operational commands.
[4] A.M. File S. 45193.

need for a high capacity bomb of, say, 1,000 lb., supporting his claims with a paper dealing with the operational and technical aspects of existing bombs in relation to their employment in certain plans in the event of war.[1] In addition, a report on U.S. Army Air Corps bombing trials (1928) proving the superiority of 1,100 lb. bombs over those of 600 lb. against reinforced concrete bridges, was submitted.[2]

Several months elapsed whilst the advantages and disadvantages of the project were examined during which time the original design for the 1,000 lb. G.P. bomb was brought up to date regarding overall dimensions to fit new bomber aircraft, as well as fuzing components and other technical details. It was then agreed by the Air Staff in December 1938 that such bombs should be produced as soon as possible, and that a 2,000 lb. size should be developed but at lower priority to the 1,000 lb. bomb.

The requirements for the 1,000 lb. bomb could be met fairly easily, most of the modifications to the existing design were simple, but one which would involve detailed trials was that of fitting the snap-on tail units so successful with the smaller bombs. This entailed a slight difference in the bomb shape at the tail end, so ballistic trials with half-scale models were carried out at Martlesham Heath in April 1939. The results were highly satisfactory, but it was decided to confirm these with full scale trials when sufficient experimental bombs were available.[3]

In June 1939, small orders for experimental 1,000 lb. bombs were placed with two firms without previous experience of such work. This was in accordance with the policy of investigating the trade facilities for manufacturing the bombs in both forged and cast steel.

By November 1939, the Armament and Aircraft Experimental Establishment had moved from Martlesham Heath to Boscombe Down, where, in the same month, the first H.E. filled 1,000 lb. bombs were used in air trials; briefly the objects of these trials were :—

(*a*) To test the ease and efficiency of fitting the tail units.

(*b*) To check the suitability of the bomb-carriers.

(*c*) To obtain ballistic data in comparison with $11\frac{1}{2}$ lb. practice bombs.

(*d*) To test the functioning of the bombs fuzed for direct action or delay.

The results indicated that the new bombs were easy to prepare for use, stable in flight, and functioned efficiently. The carrier, a type designed at the Royal Aircraft Establishment for bombs up to 2,000 lb. weight, would be suitable after minor modifications.

Meanwhile the completed bomb design had been approved in August 1939 in anticipation of the success of these trials. Large scale production was put in hand in December 1939, but as there were serious limitations in forging capacity, a large proportion of such industry being required for A.P. and S.A.P. bombs, the bulk of the G.P. bomb production had to be done by casting.[4]

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[1] Plan W.4—concerning the disruption of enemy communications in an advance into Western Europe. Plan W.5—concerning the maximum possible reduction in the German war potential in the Ruhr, Rhineland and Saar.

[2] A.M. File S. 45193.

[3] A.M. File S. 25514.

[4] A.M. File S. 46970.

Development of 1,900 lb. and 4,000 lb. bombs

Following the Air Staff decision in December 1938, design work for the next size in G.P. bombs went ahead although, as already stated, on a much lower priority than for the 1,000 lb. bomb. In January 1939, after detailed consideration regarding installation and carriage problems, the requirements were based on a bomb to weigh some 1,800 lb. with 80/20 amatol filling. Certain restrictions in overall dimensions, necessary for correct stowage in the aircraft then being built, limited the weight, but this was acceptable.

An outline of the design was completed by the Design Department in February 1939 which showed an approximate charge/weight ratio of 26 per cent. This design was then reconsidered in relation to the bomb-carrier position, and in the following August authority was given by the Air Staff to go ahead with development on these lines. A month later it was found that to allow for the tail crutch, the bomb body had to be slightly lengthened with an increase of weight at the nose to balance this extension. The bomb therefore became heavier, the calculated weight being 1,880 lb., and because of this it was in future known as the 1,900 lb. bomb.

The first experimental bombs were ordered by the Director of Armament Development (D.Arm.D.) in December 1939, an innovation being that none were to be inert-filled as it was anticipated that all ballistic data could be obtained from air trials with live bombs.[1] In February 1940 this order was increased and placed on the highest possible priority. Good progress was made and by 3 August 1940 static detonation trials had been completed and the design approved. Later in that month the bombs were successfully air tested at Boscombe Down. Although the programme of trials was not completed, Air Staff considered the results warranted commencement of production, a probable interference with 1,000 lb. bomb output being accepted.[2]

When in September 1940 a more detailed examination of the fragmentation trials was completed by C.S.R.D., it was discovered that the 1,900 lb. bomb had a lower order of explosive efficiency than the 1,000 lb. size. Fragmentation was coarser, due to increased case strength to secure greater penetration power. The charge/weight ratio was 26 per cent. as compared with 37 per cent. in the smaller bomb, and any effective increase could only have been obtained by a reduction in the thickness of case by forging. As with the 1,000 lb. bomb however, the bulk of production had to be in cast steel and so the case thickness had to remain the same.[3]

By December 1940, the German bombing offensive against this country had provided a wealth of information on the effectiveness of bombs against built-up areas, bridges, railways and public services. Comparison of the results of such bombing with that obtained with G.P. bombs against similar enemy targets, left no doubt as to the inefficiency of our bombs, and yet, as will now be related, another type of G.P. bomb—4,000 lb.—was to be developed.[4]

Events began with the Air Member for Development and Production requesting the Design Department, through the Ordnance Board, to prepare on the

[1] A.M. File S. 50362.

[2] A.M. File S. 45193.

[3] O.B. Proc. 8824.

[4] A.M. File C.S. 7557 and this volume, Chapter 11.

highest possible priority a' design for a 4,000 lb. bomb on similar lines to the G.P. series.[1] Some brief requirements for such a bomb were as follows :—

(a) To be of similar size to the 4,000 lb. H.C. bomb (then being developed).

(b) Of the highest charge/rate ratio possible.

(c) To withstand impact with a modern mult-storied building or metalled road from 2,000 feet.

(d) Nose and tail fuzing.

(e) Ballistic performance similar to existing G.P. bombs.

By Februrary 1941, a preliminary design had been completed providing for a 30 per cent. charge/weight ratio of 50/50 Amatol or pure T.N.T. depending on the supply position for the latter ; the case thickness being 1¼ inches. This design was discussed at a meeting of representatives of the Air Staff, Ministry of Aircraft Production[2] and Ordnance Board on 22 March, when it was considered to be satisfactory, and that Air Staff approval for development should be requested.

In a minute to the Director of Operational Requirements (D.O.R.) the same day, the Director of Armament Development outlined the technical details of the proposed bomb. Among other matters it was stated that the bomb would be suitable for stowage in the most recent bomber aircraft and that production capacity could be obtained without difficulty. An early decision was requested as to Air Staff opinion on the development of the bomb.

At that time there appears to have been no clear-cut policy regarding future large bomb development. Among many considerations the question of maximum size of bombs was receiving considerable attention and in this matter in particular there was no state of unanimity. In enquiries, lasting some two months D.O.R. asked for more information as to what might be expected from such a bomb. Such enquiries only produced from D.Arm.D's. staff the recommendation that damage to industrial targets would be more severe than with smaller bombs and that suitable aircraft existed for carriage of the large bomb.

From the opinion of various scientists in the Ministries of Aircraft Production and Home Security. D.O.R. was advised that it appeared to be uneconomical to develop such a bomb owing to its small charge/weight ratio. The decision was therefore made that further experience with the 1,000 lb. and 1,900 lb. bombs was necessary before the 4,000-lb. bomb could be considered as an operational requirement.

The Ministry of Aircraft Production was informed of this in May 1941, but meanwhile on 17 April, D.Arm.D. had placed an order for two hundred experimental bombs and asked the Design Department to prepare a method of filling. D.Arm.D. had carried his point so far but in the following June, Air Staff again pointed out that there was no official requirement for the bomb and the Controller of Research and Development (C.R.D.), ordered that development work should cease except for twelve bombs. D.Arm.D. persisted however, pointing out that all arrangements for casting had been made, and eventually it was agreed that forty-four bombs from each of two contractors should be completed ; a total of one hundred in all.[3]

[1] M.A.P. File S.B. 13743.

[2] All armament research and development was transferred to the Ministry of Aircraft Production on its formation in May, 1940.—Cabinet File 19/4/120.

[3] A.M. File C.S. 8698.

Two of the first batch of experimental bombs were inert filled and tested in installation trials at Boscombe Down in January 1942. Stowage of two bombs in the Halifax aircraft would be satisfactory if a slight modification to close the bomb doors was made. The installation of one bomb in the Lancaster aircraft would be satisfactory after slight adjustment to the carrier.[1]

So far no functioning or ballistic trials had been held, but on 31 March 1942, the A.O.C.-in-C. Bomber Command wrote to the Air Ministry asking that 'the production of a reasonable quantity of 4,000 lb. G.P. bombs be pressed on with forthwith.' His letter continued :—

'We have at present no really large bomb capable of taking delayed action fuze. On the other hand it is apparent that for the accurate destruction of individual objectives such as important factories, really low attacks are essential. Such attacks cannot be carried out without delayed action fuzing. My proposal is in future—when such a bomb becomes available—to combine the blitzing of a town with ground level attacks by a few selected aircraft with 4,000 lb. bombs and delayed action fuze of 11 seconds on points of individual importance.' Finally he asked for an initial stock of five hundred bombs to meet the estimated requirements of the next six months.[2]

The idea behind the eleven seconds delay was to give the bombing aircraft time to get away before detonation, and not necessarily to obtain deep penetration. For the type of attack contemplated the 4,000 lb. bomb would probably be as effective as a similar weight of smaller bombs, and therefore there was an immediate revision of the previous Air Staff ruling that development should cease.

It was agreed that there was a need for the bomb and D.Arm.D. was asked to go ahead with a development order to meet the Command's immediate requirements, while the normal machinery of provisioning was put in motion. If necessary there would have to be a reduction in output of 1,900 lb. bombs in order to have sufficient replacements for the 4,000 lb. H.C. bomb, which was suspect of break-up on impact, and consequent failure to detonate.

The original experimental order was still in progress and from this eighty-eight bombs were at once earmarked for operations in Bomber Command. In April 1942, fourteen were available, a further sixteen would be ready in three weeks and the remainder could be produced at twenty per month. By reducing 1,900 lb. bomb production the Director of Armament Production estimated that the additional four hundred bombs required could be produced in nine months.

In May 1942, successful ballistic and detonation trials were completed at Boscombe Down, and the filling of bombs for operational use began. On the recommendation of the Static Detonation Committee the filling was to be a mixture of 60/40 Amatol and R.D.X./T.N.T. 60/40 in the proportion 85/15 by volume.[3] The bomb was approved by Air Staff for service use in July 1942 by which time the production forecast had been raised to eighty-five per month.

Production continued smoothly if slowly, with only minor troubles in casting and other manufacturing difficulties, but output never reached the anticipated monthly figures. Fortunately by March 1943 Bomber Command had decided

[1] M.A.P. File S.B. 13743.
[2] A.M. File C.S. 8698.
[3] A Committee formed in the Ministry of Supply, December, 1941. O.B. Proc. Q. 593.

that a total of two hundred bombs would meet their requirements. This decision arose from the advent of a new bomb the 4,000 lb. M.C., and in the following month the Ministry of Aircraft Production was instructed to cease manufacture.[1]

A total of two hundred and seventeen 4,000 lb. G.P. bombs was expended in operations by Bomber Command, on which no definite results were assessed. It is significant, however, that on 12 May 1942, the Air Officer Commanding-in-Chief wrote, after asking for the 4,000 lb. M.C. Bomb :—

> 'I am aware that the 4,000 lb. G.P. and 4,000 lb. H.C. bombs are already available, and also that they can be used for low attacks. Unfortunately both bombs possess limitations which seriously reduce their efficiency. The 4,000 lb. G.P. bomb suffers from the defect common to all bombs with a heavy cast steel case, in that its charge/weight ratio is too low, and the filling is sacrificed for metal to an extent which is unprofitable in the case of the targets I have mentioned.'[2]

The production of the 4,000 lb. G.P. was pressed forward by a Technical Department (D.Arm.D.) without the considered approval of the Air Staff, represented by the Director of Operational Requirements. It cannot be said to have been entirely valueless—no H.E. bomb released over enemy country is completely without value—but the time, labour and material expended on its production could have been more profitably used. It is probable that had the effects of various types of bombs been more efficiently examined during the years before the war, the bomb would not have been manufactured. It did, in fact, suffer from the same disability as its predecessors—it was neither strong enough for complete penetration from great heights of resistant targets, nor was it explosive enough to justify its weight and bulk.

Conclusion

Operational experience with the G.P. bombs in the 1939–45 war soon showed that the whole range suffered from one overwhelming disadvantage, insufficient explosive contents.[3] The average charge/weight ratio was between 27 per cent and 30 per cent. and that was of comparatively inefficient high explosive. To produce a range of bombs for all purposes had inevitably been shown to result in such bombs being efficient for none. The project was no doubt the only one possible in peace when money for research, development and production was extremely limited, and many useful lessons in design and production were probably learned, but as a weapon of war the G.P. bomb can only be described as partially satisfactory.

The figures for G.P. bombs dropped by Bomber Command in operations during the 1939–45 war are shown below ; they give some idea of the quantities used in the service. The huge total of 500 lb. bombs for instance, was only used because sufficient quantities of the more efficient M.C. bombs, were not available and a glance at the figures for 500 lb. bombs for 1944 might suggest that by that time the G.P. bomb was back in favour. On the contrary, this enormous rise in bomb expenditure is accounted for by the great demand for 500 lb. bombs in tactical operations during the invasion of Europe. Such demands could only be met by the use of these obsolete G.P. stocks[4] ; this

[1] A.M. File S. 80115.
[2] A.M. File C.S. 14772. The targets referred to were 'aircraft and engineering factories and shipbuilding yards.'
[3] A.M. File C.S. 7557 and the Report on Weapon Effectiveness. D.G. Arm W.E./S.3507.
[4] *See* this volume, Chapter 11.

became increasingly apparent in 1944 and 1945 due to Bomber Command's critical shortage of '1,000 pounders', even the 500 lb. G.P. stocks had to be conserved involving the operational use of the 250 lb. G.P. series which were largely expended on the flying bomb sites in Northern France where they unfortunately proved almost totally ineffective.

Year.	4,000 lb.	1,900 lb.	1,000 lb.	500 lb.	250 lb.	40 lb.	20 lb.
1939				29	50		
1940			153	20,106	61,572	26,179	2,132
1941		482	10,447	65,341	34,692	4,650	192
1942	1	1,241	14,409	29,482	15,206	6,938	
1943	40	28	36,182	13,659	3,188	5,172	500
1944	176	366	20,845	395,641	7,768		2,116
1945		24	128	27,076	27,180		
Total	217	2,141	82,164	551,334	149,656	42,939	4,940

CHAPTER 2

THE BUOYANT ('B') BOMB

Early development

The primary object of the 'B' bomb was to attack the bottom of a ship. The deck of a capital ship is protected from ordinary H.E. bombs or shell by armour, its sides are protected against torpedo attack by blisters, but no attempt is made to give special protection to the bottom. A device therefore for attacking a ship at its weakest part was attractive, and it was not surprising that suggestions for a weapon for this purpose were made early in the first world war.

The first of these appears to have been made by Lieutenant H. A. Williamson, R.N. in 1914 but no serious effort to put it into practice seems to have been made until 1923, when Wing Commander T. R. Cave-Brown-Cave, commanding the Marine and Armament Experimental Establishment at Isle of Grain, made proposals to the Director of Research, Air Ministry, for the development of a buoyant bomb. His idea was that the bomb should be made in two parts, a floating component and a suspended H.E. component. The two would come apart on impact, and the bomb would thus be suspended under water at a suitable depth. The H.E. component was to be detonated, either after a fixed delay, or by contact with the ship of the floating portion, or by combination of these. This device was rather more in the nature of a mine than a bomb, but the notion of having a buoyant bomb dropped in such a position that, on rising to the surface, it strikes the bottom of the ship, was a natural development.

The advantages of such an attack were obvious: by dropping a number of these bombs at the correct distance ahead of a ship it was claimed that no amount of manoeuvre could prevent at least one of them from inflicting damage: the explosion of a bomb at a considerable depth would be in itself more effective than one near the surface: and no sweeping would be possible, as with mines. Wing Commander Cave-Brown-Cave asked for patent rights to be considered.

The bomb in this original conception was given the name 'Leader' Bomb. Its development in the form suggested by Wing Commander Cave-Brown-Cave was not pursued. The Director of Research placed the idea before Mr. H. E. Wimperis, at that time Superintendent of the Air Ministry Laboratory at South Kensington. One of his assistants, Captain Horsley, who played a prominent part in the design of the Course Setting Bomb Sight, and whose death a few years later was a great loss to the Armament Branch, put forward a simple alternative to the Leader Bomb, in the shape of the self contained and truly buoyant bomb. Some experiments with the Cave Leader Bomb were however completed at Grain using converted 520 lb. light case bombs.

During 1923, extensive investigations went forward at the Air Ministry Laboratory, and by July a preliminary Report was prepared, giving theoretical figures for under water trajectory, maximum depth reached, and delay necessary to detonate on upward path, at 35 feet. Experiments with models in a water tank confirmed these figures. Arrangements were put in hand for full-scale trials with a 520 lb. bomb, with modified terminal velocity and density.[1]

[1] Air Ministry Laboratory Report A.1034. July 1923.

The Report outlined the advantages of this form of attack, and made the claim that the new bomb might be considered as fifteen times more damaging than an ordinary H.E. bomb of similar weight. Figures were given for the best point of aim and some suggestions for mechanical design added. At this stage the idea of a fixed delay before detonation was uppermost. Later, as will be seen, the bomb was fitted with sensitive horns like a mine, so that the ship might bring about its own destruction. Two important facts were established during this preliminary research—

(*a*) The time of descent through water was reasonably constant for all ordinary heights of release.

(*b*) The depth/time curve was as reasonably independent of any height above 2,000 feet.

In August 1923, a second Report was issued by the Air Ministry Laboratory giving an account of model experiments in a tank which confirmed the theoretical figures already arrived at.

In January 1924, a further Report was issued by the Air Ministry Laboratory giving new suggestions for design, with comments on the results of full scale experiments at Grain where two methods for retarding the bomb's upward velocity had been suggested ; firstly by means of flap secured to the tail, and designed to open as the bomb ascended, and secondly by means of ' water-logging ' or allowing a compartment of the bomb to fill with water after reaching maximum depth. The first method was calculated to be unsatisfactory and the second considered worthy of experiment.[1]

It had by that time been decided that 50 feet was the best maximum depth for the bomb, and this limitation was then stated to present ' the only real difficulty '. An important sentence in the Report runs as follows :—' It should be emphasised that a solution of the problem, for the size of bomb now being experimented with, has but a limited value unless it can be applied directly to bombs of 2,000 lb. or more '. During the following twenty years, except for a brief period at the commencement, the weight of the ' B ' bomb was 250 lb.

So far such full scale experiments as had been completed had employed existing bomb cases of the 520 lb. type, but early in 1924, the Director of Research at the Air Ministry decided that a new body must be designed for this special purpose. The production of the necessary details was entrusted to the Air Ministry Laboratory by whom, in March 1924, the design of a bomb was submitted. It was a cylindrical case, 9 feet long and 18 inches in diameter, with a conical head and drum tail, which had a diameter of 27 inches, and was to have a total weight of 1,000 lb. when filled.

About that time the Admiralty began to be interested in the work and the Naval Director of Scientific Research (N.D.S.R.), asked in March 1924, for details of the proposed bomb and for a 1/40 scale model, which was duly supplied by the Air Ministry Laboratory. With this N.D.S.R. proposed to make a series of experiments to determine whether the disturbance of water beneath and surrounding a moving ship would prevent a ' B ' bomb from hitting the bottom. The results were good, and it was established, experimentally at least, that the ' sweeping away ' effect of the moving ship was negligible. At the same time the mathematical work which had led to the early design was reviewed and approved by the Admiralty.

[1] A.M. File S. 22795.

The preparation of full-scale experimental bombs of Air Ministry Laboratory design was entrusted to a civilian firm from whom four were ordered. These were ready by January 1925 and were sent to Gosport, where future 'B' bomb experiments would be undertaken. In the meantime the Chief Superintendent of the Research Department, Woolwich, had been consulted about the best method of initiating the detonation of the bomb and of filling it. He was further asked to design suitable fuzes for both nose and tail. The anti-submarine bomb fuze was suggested as a possible nose fuze as detonation on deck impact was visualised, as well as delayed detonation after entering the water, although it was never intended that the bomb should hit the ship directly.

A meeting was held at the Admiralty on 13 February 1925 at which D.D.R.(Arm.) and representatives from various Branches of the Admiralty were present, and Air Ministry policy for the development of the bomb was outlined. No suggestions appear to have been made by the Admiralty representatives for modification of the proposed designs, but it was at this meeting that the name 'B' (Buoyant) bomb was officially adopted. The only other point of interest was that horns, similar to those fitted to mines, were suggested by the Deputy Director of Armament Research to be fitted in the tail of the bomb, as a secondary initiating device in case of failure of the fixed delay system, or for bombing from very low heights.

Early in 1925, interesting experiments with model bombs were undertaken by Mr. A. P. Rowe, in the Admiralty tank at H.M.S. *Vernon*, as a preliminary to full-scale experiments. The object was to calculate the terminal velocity of the bomb in air and the maximum depth to which it might be expected to descend. On 25 April 1925, the first full-scale trial was completed at Stokes Bay (Gosport), the bomb being fitted with a depth recorder and released from 500 feet at a ground speed of 49 m.p.h. No definite conclusions could be reached from the record of one bomb but theoretical figures were verified, and the Portsmouth tank experiments with a model shown to be directly applicable to the full-size bomb.

Trials continued at Gosport and brought to light deficiencies in the structure of the bomb, particularly in the tail, which was distorted or torn off on impact. This tail was fitted with a retarder ring to keep down the terminal velocity of the bomb, and this ring was thought to be responsible for the distortion. Mr. Rowe suggested removing the ring and increasing the diameter of the nose, and R.A.E. agreed, but in the meantime, however, Mr. Rowe had developed another plan. This was to make the tail so fragile that it would inevitably become detached on impact. The diameter of the bomb had been fixed at 18 inches to resemble the torpedo for carrying purposes, and the explosive content at about 600 lb. Mr. Rowe now suggested a bomb of 840 lb., with a strong cup-shaped nose and a light tail just sufficiently large to give stability in air. As an alternative he suggested a tail-less bomb weighing 1,080 lb. which, at this weight, he calculated would be stable in air, with a cupped nose of 21 inches diameter. To decide which of these designs was most promising for development, a conference met at Air Ministry on 11 February 1926 with D.S.R., D.D.R.(Arm.), a representative from R.A.E. and Mr. Rowe. It was then decided to adopt the second type mentioned above.[1] In a letter to

[1] A.M. File S. 22795/2.

R.A.E., D.S.R. gave what were then considered the basic details of design: these were :—

Weight, 1,080 lb.
Sp. Gr., 0·98.
T.V., 600 f.s.
Shape, Cylindrical: the design of the nose to be left to experiment.
Main filling to be contained in the nose.
The weight of the case to be as low as possible.
The bomb to be able to withstand impact with water with a deceleration of 800 g. and to be watertight at 80 feet.

By April 1926, R.A.E. had produced a design on these lines with an explosive content of 584 lb. or about 60 per cent. charge/weight ratio.

An experimental bomb was completed by a civilian firm in March 1927 and tested by dropping in the sea from 3,000 feet off Portsmouth in May. The bomb reappeared on the surface after about 19 seconds immersion. In a second trial the bomb was dropped from three heights: 1,500, 3,000 and 6,000 feet. From the last it suffered some damage, but the flight of the bomb was apparently stable.

During the remainder of 1927 and during 1928 various dropping trials took place at Gosport and small modifications to the original design were made. On 18 July 1928 a letter was addressed to the Admiralty, of which the following is a summary :—

> 'The Air Council has under consideration the tactical use of a buoyant bomb, and has ordered the production of a small number of present design for experiment. Tests already completed show that the bomb, without a fuze, will stand up to impact on water from 6,000 feet. With the addition of the fuze designed by Woolwich, weighing some 15 lb., impact from heights over 1,000 feet may destroy the buoyancy chamber. There are disadvantages in increasing the strength of this, and for these reasons 1,000 feet must be regarded as a temporary maximum for initial design. The Air Council considered that low height attacks would in any case be preferable.'

With these views the Admiralty concurred, adding that exercises at sea were necessary to decide the best tactical method of using the bomb. They were willing to accept the 1,000 feet limit for these in the first instance. The Naval Torpedo and Mining Department (H.M.S. *Vernon*) were also designing a fuze for the bomb, which would be much lighter than the Woolwich fuze.[1]

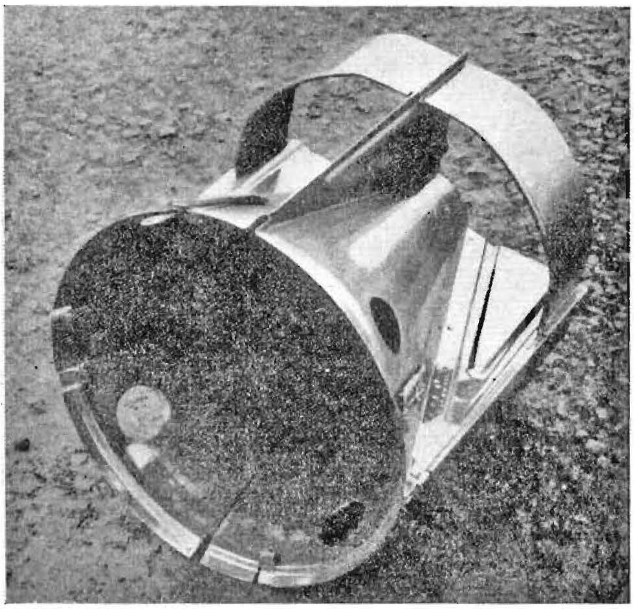
During the whole of this bomb development period, the Design Department had been at work on the design of a suitable fuze mechanism for the bomb. The principle of a fixed delay had by now been abandoned and the bomb was to explode on contact with the ship. By the beginning of 1929 a fuzing method had been designed combining an air-vane safety mechanism with the movement of a sleeve on impact: the movement of the sleeve was designed to close a battery circuit: deceleration of the bomb in water moved the sleeve and made 'live' a number of 'whiskers' protruding from the bomb: contact of the side or bottom of the ship with these fired the H.E. charge. Concurrently with this the Torpedo Section at Gosport was engaged in the design of an electric firing device.

[1] A.M. File S. 22795/3.

During 1930 numerous trial drops with dummy bombs were made at Gosport to test firing mechanism, and in that year two important papers were produced. The first described an investigation into the under-water trajectory of the bomb by Mr. A. P. Rowe and Mr. Ivor Bowen. The method used by Messrs. Rowe and Bowen was to photograph the bomb just before entry with a high-speed cinematograph camera: its progress through the water was measured by photographing a drogue attached to the bomb by a 30-feet cord. By this means it was hoped to obtain data for the first 40 feet of immersion (the bomb was 10 feet long). Much valuable information was obtained from these experiments, which were carried out off No Man's Fort, in the Solent.[1]

The second paper dealt with impact shock on the nose of the bomb. This problem had proved the most difficult to solve in the design of the bomb case and constant fracture of the nose had occurred. The experiments on models by Dr. R. G. Harris of R.A.E. (R.A.E. Report No. 889—October 1930) showed that reduction of shock could be obtained by using a nose with a rounded conical protuberance.

In 1931, the design of the bomb was sufficiently advanced to justify trials against a moving ship. By this time considerable detail work had been completed at Gosport on the design of dummy bombs for practice purposes, with audible firing devices which would indicate a hit under water, and firing circuits.

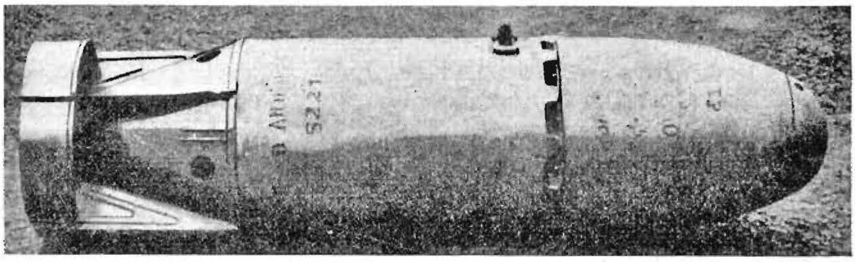


SHORT TAIL FOR "B" BOMB

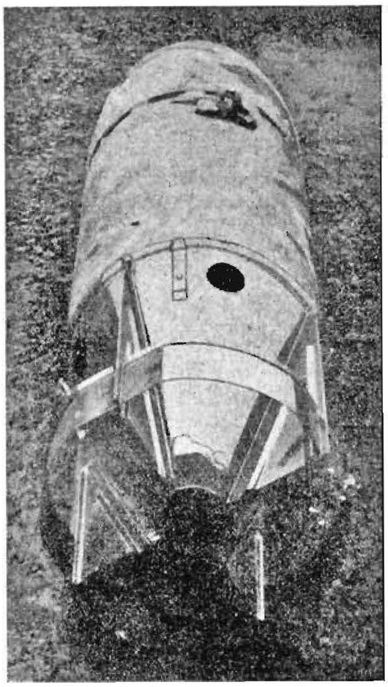
The first sea trials of the bomb against H.M.S. *Iron Duke* were completed on 24 February 1931. The object was to ascertain the effect of a moving ship on the under water path and the performance of a 'B' bomb. The trial was to some extent tactical for it sought also to investigate the possibility of dropping the bomb in the right place ahead of the ship, but the tactical side was not

[1] A.M. File S. 22795/4. Apart from its application to 'B' bomb research, this Report contains most valuable data on the use of drogues for measurement of u/w path.

emphasised and no special training seems to have been given to the crews. Bomb aiming was in fact assisted from the deck of the ship ; observations were visual and by cinematograph. Ten bombs were dropped and the conclusions reached were that it was possible to drop a ' B ' bomb in such a position ahead of a ship that it would come up and strike the bottom : that there was no evidence of 'sweeping away,' and that the under water path was approximately vertical in both descent and ascent.



SIDE VIEW OF "B" BOMB WITH SHORT TAIL. FUZING LINK NOT FITTED



REAR VIEW OF "B" BOMB WITH SHORT TAIL. FUZING LINK NOT FITTED

Further trials were arranged against H.M.S. *Centurion* later in the year. This ship was used as a target for the assessment of ordinary precision bombing but it was agreed between the Air Member for Supply and Research (A.M.S.R.) and Air Staff that the ship might be used for a short period each day for low height ' B ' bomb attacks by aircraft from the Torpedo Development Flight, Gosport. Accordingly eighteen bombs were dropped against the ship between 7 and 12

September 1931, from 300 feet. A special report was submitted by the Captain of the *Centurion* to the Admiralty which indicated that out of the eighteen bombs dropped, nine were possible hits. At the subsequent 'B' Bomb Conference (3 November 1931) it was concluded :—

(*a*) A correctly aimed bomb would hit the bottom of a ship.

(*b*) There was no evidence that the under water trajectory was adversely affected by the movement of a ship.

It was unfortunate that the sea water energised batteries failed during these trials, owing to too long storage before use. However, the trials gave rise to a Conference at Admiralty in February 1932 to discuss the future of the bomb.

A letter from A.M.S.R. (Air Vice-Marshal Dowding) to Vice-Admiral Backhouse written on 3 February is illuminating.

After preliminary remarks it reads :—

> 'There are four distinct questions to be answered about the 'B' bomb.
>
> (*a*) Will a bomb coming up underneath a ship hit it, or will it be deflected by the current formed by the passage of the ship ? The results of the recent *Centurion* trials show that the bomb will probably hit the ship.
>
> (*b*) Will the bomb go off when it hits ? This was not proved in the trials owing to the failure of the sea batteries.
>
> (*c*) What will be the effect of the explosion, remembering that the buoyancy chamber comes between the ship and the charge ?
>
> (*d*) What hitting effect can be sacrificed if the bomb is aimed ahead of the ship and avoiding action is easier ? (The bomb is not streamlined and has no fins.)
>
> When we have the answers to these questions we can decide whether the 'B' bomb should be adopted as a regulation weapon. Until that time discussion is fruitless.

The Conference was duly held in February 1932, but led to no fruitful decision, except that more trials were necessary. But none took place until 1937, when H.M.S. *Bacchus* was used as a target ship ; and A.M.S.R.'s questions (*c*) and (*d*) remained unanswered.[1]

In the interim, however, the development of the bomb had undergone a radical change. The original size and shape of the bomb had been decided largely with the torpedo as a model : thus there was nothing to indicate that either the shape or the size was the best for this particular purpose. Indeed there were good reasons to the contrary. A bomb of this size could only (in those days) be carried on an aircraft designed to carry a torpedo : in a bomb of this shape the charge was a considerable distance from the ship when the nose was in contact, and the bomb being a cylinder with no fin tail, its shape was ballistically bad in air. It was realised that the following improvements could be made in a re-designed bomb :—

(*a*) Decrease in the distance between the charge and the ship's bottom at the instant of detonation.

(*b*) Increase of charge/weight ratio.

(*c*) Decrease in maximum depth reached.

(*d*) Improvement in air trajectory by increase of terminal velocity.

[1] A.M. File S. 29262.

Accordingly in April 1931, R.A.E. had been instructed to investigate possible improvements in bomb shape, although no decision was taken at that time about weight. Considerable research at R.A.E. during 1931 and 1932 produced a promising design, which resembled much more closely the standard bomb design. Particular attention was given to the shape of the nose, to give good flight in air and minimum entry shock. As large drag under water was essential after impact to prevent the bomb from descending too deeply, the nose was designed to break away after impact, revealing a cup-shaped permanent nose. In May 1932, models of the new design were released from aircraft: its air stability was good: and both nose and tail came off on impact.[1]

The question of the ideal size of the bomb then occupied the minds of the Research and Technical staffs at the Air Ministry. Two sizes in addition to that already under development were suggested: 500 and 250 lb. To assess the relative damage from the three sizes, trials in 1932 and 1933 were conducted with scale models of one-third actual size against a built-up structure of a section of H.M.S. *Nelson* attached to H.M.S. *Roberts*. The resulting damage was assessed by the Admiralty as 'serious' for both the 1,100 lb. and the new 250 lb. design, and, at a later date as 'promising' for the 500 lb. design. From 1933 onwards the 250 lb. design was given more and more attention and no more need be said of the 1,100 lb. size, which was finally abandoned in that year.

Some ten years of research and experiment had been spent on the development of this bomb, but it has to be remembered that much of this time was devoted to accessories, and to the design of training and practice types. The experience gained was of great value in the development of the new type. It may appear unfortunate, however, that the difficulties which were still being experienced, particularly in the design of an efficient and reliable electric battery, did not encourage the designers to abandon electric fuzing with all its attendant disadvantages of dirty or broken contacts and constant maintenance. The struggle was in fact to continue for another sixteen years, until the whole system was scrapped and a re-designed bomb with a mechanical fuze introduced.

The 'B.2' bomb

The new design of 'B' bomb was given the name 'B.2' and had been undertaken by R.A.E. at the request of D.S.R. in April 1931.[2] At the same time a monthly meeting was inaugurated at Air Ministry, of 'B' bomb experts who were responsible for the technical development and testing of the bomb and its various parts.

For the next ten years work on the 'B.2' and its various components went forward at R.A.E. and Gosport. Unstinted help was given by H.M.S. *Vernon*, particularly in the study of under-water characteristics, requiring a very large experimental tank, which only *Vernon* could provide. Quantities of completed bombs were issued to Bomber and Coastal stations at the outbreak of war in 1939 but there is no record to show that the bomb was ever used against shipping. A proposal by Coastal Command towards the end of 1940 to use the bomb as a floating mine in confined waters was considered but not carried into effect, although a few bombs were modified for this purpose, and in 1942 a suggestion was made by the Armament Department of R.A.E., that bombs already manufactured might be used for demolition purposes. This proposal came to nothing and eventually the bombs were reduced to produce.

[1] R.A.E. Report BA/R. 221/4 in A.M. File S. 29262.
[2] A.M. File S. 30162.

CHAPTER 3

ANTI-SUBMARINE BOMBS

In April 1917, German submarines were sinking Allied shipping at the average daily rate of 28,000 tons. The seaplanes and flying boats of the R.N.A.S. were doing all in their power to check this menace, but no effort seems to have been made to design special bombs for the purpose. It was realised that for maximum under-water detonation, the maximum amount of explosive, and the minimum amount of metal were desirable, and 'light case' bombs had indeed been designed weighing 230 lb. and 500 lb. for general under-water use. These were poor in shape and bad ballistically. The smaller seaplanes could only carry the 65 lb. and 100 lb. bombs, and these were, therefore the ones mainly in use.

In 1924 a 'Bomb Conference' was held at the Admiralty at which a requirement was agreed on for two new light-case bombs of 250 lb. and 500 lb., for use against submarines. The Superintendent of Design, Woolwich, was asked to prepare suitable designs by D.D.R. (Arm.) who suggested a preliminary design himself. The bomb was to follow the General Purpose bomb contour, but to have no central tube and a stronger tail (weak G.P. tails had given trouble in handling). The explosive content of the new bomb was to be in the neighbourhood of 53 per cent. compared with something under 30 per cent. for the G.P. bomb.[1]

A year later, at a further conference, the Admiralty asked for a third bomb of this kind to weigh 100 lb.[2] This was a purely Naval requirement, and marked the beginning of a controversy about the best size of anti-submarine bomb. There was, however, no dispute about the kind of bomb required. An under-water explosion to be effective demands the largest possible quantity of explosive at the least possible distance from the target. The case of the bomb need therefore, only be strong enough to prevent the H.E. filling from breaking up when the bomb strikes the water.

Unfortunately these two essential requirements were, to a large extent, opposed in the choice of size for the bomb. If there could always be a certainty of placing the bomb within a few feet of the submarine's hull on the first attack, then one bomb of the largest possible size which could be carried would be the ideal. But the submarine is a difficult target, and moves like the aeroplane in three dimensions. The chances of hitting it are therefore increased by using a number of smaller bombs, either singly, on renewed attacks, or in a salvo or 'stick'. Single repeated attacks were usually not possible so that the 'stick' method became eventually the standard method of attack ; the problem then became one of deciding what was the smallest bomb worth while using. At that time the Admiralty favoured 100 and 500 lb. ;[3] and the Air Ministry 250 and 500 lb.

The original request (for the 250 and 500 lb. size) went to the Design Department in January 1925. Three months later a sketch of the general design to be followed was sent to the Ordnance Committee with a request for information on what thickness of wall would be necessary to withstand impact on water

[1] A.M. File S. 23954.
[2] O.C. Memo B. 9045/25.
[3] Annual Bomb Conference, Admiralty, 17 July 1924.

from 6,000 and 2,000 feet. The Ordnance Committee pointed out the difficulties in obtaining this information, suggesting that the only practical method was to drop bombs of varying thickness in deep water and recover them by means of divers, and D.D.R. (Arm.) therefore decided to go ahead without trial, using a thickness of case which would give a 51 per cent. explosive content. Later the Committee submitted a scheme for testing bombs in which a buoyancy chamber in the bomb would be freed on impact and would come to the surface, bringing with it a length of wire attached to the bomb, but this scheme did not receive the approval of D.D.R. (Arm.) and was apparently dropped.

At a further Bomb Conference in 1925 the Admiralty decided that they would not require the 250 lb. size, but the Air Staff decided to retain it ; the design of three sizes of A.S. bomb therefore went forward concurrently from that date, the 100 lb.[1] size being regarded as the most urgent.

Development of the 100 lb. A.S. bomb

By the end of 1926, six 100 lb. bombs had been manufactured and fitted with a type of tail which had been found during the development of the G.P. bomb to stand up to rough usage. Five of these filled T.N.T. were dropped on water at Orfordness from 4,000 feet, and of these, four detonated successfully. No effort was made to observe the order of detonation, and the sixth bomb was sent to the Superintendent of Experiments at Shoeburyness for observed detonation under water. This experiment was made in May 1927, but the effect of detonation was measured only by examination of the fragments, and though it was considered ' satisfactory ', no kind of ' target ' was used.[2]

Considering that the bomb was being designed to combat, in future wars, what had been acknowledged as probably the greatest single menace employed by the enemy, it is strange that greater efforts were not made at this stage of design to measure the effect of detonation on the structure of a submarine. It was not until twelve years later, when the same menace had risen again, that the bomb was tested and found to be wanting. A careful study of the history of this and other bombs of the period, leaves the impression that far more attention was paid to trifling details of manufacture, paint, colour and marking, than to the question of whether the bomb was an efficient destructive agent against the kind of objective for which it was designed.

The question of the best type of H.E. filling for the new bomb arose at this time. It was indeed under review by the Armament Staff and C.S.R.D. for all bombs, and at a conference in the department of the latter early in 1927, the explosives experts put forward the theory that complete detonation with a pure T.N.T. filling in a light-case bomb was doubtful. The standard filling for aircraft bombs was Amatol, but this was unacceptable for bombs to be carried in H.M. ships owing to its tendency to corrode brass, and to exudation in hot climates. The alternative filling proposed was Baratol (Barium Nitrate and T.N.T. in the proportion of 10 per cent. to 90 per cent.), detonation being much more readily propagated through this explosive than through pure T.N.T. To this proposal D.N.O. agreed, provided Baratol proved suitable for ship storage, although he gave the opinion, backed by experiment at H.M.S. *Vernon*, that T.N.T. was quite efficient.[3]

[1] A.M. File S. 24349.
[2] O.C. Memo. B. 12835/27.
[3] O.C. Memo. B. 12725/27.

Comparative detonation trials with T.N.T. and Baratol made at Shoeburyness showed that there was very little difference between the two, Baratol being slightly less violent than T.N.T. Again fragmentation was relied on entirely to measure the value of the filling, and D.N.O. decided that T.N.T. would be the accepted filling for Fleet Air Arm bombs.[1] By the beginning of 1928, a draft specification for the bomb, unfilled, had been prepared, and passed through D.N.O. to the Master General of Ordnance for his approval. Thus a bomb had been designed in under four years. By May 1928, the design was approved by the Chief Inspector of Armaments (still the War Office authority for R.A.F. Equipment) and became 'Bomb, Anti-submarine, 100 lb., Mark I'. However, it was soon decided to replace the steel tail with one made of duralumin. This saved a few pounds in weight, important in the small aircraft of that time, but the balance of the bomb was upset necessitating a re-design of the body and alteration or replacement of the manufacturers' jigs and tools. When this decision was made it was realised that the supply of aluminium would be limited immediately war commenced with a consequent reversion to steel tails and a further upheaval in the factories and delay in production. There was, however, one important advantage in the new design, for by reducing the thickness of metal at the nose to compensate for the lighter tail, the explosive content was increased from 52 per cent. to 62 per cent.

New detonation tests for the re-designed bomb (given the name Mark II) were required, and were similar to those made on its predecessor—fragmentation at rest, and dropping in water at Orfordness. Eight specimen bombs were made by the Royal Ordnance Factory, four for each test. Two of the four bombs for fragmental trials were filled with T.N.T. and two with 10/90 Baratol, and of the bombs for dropping trials, two contained poured T.N.T. and two 'biscuit' (dry) T.N.T.

The dropping trials were completed at Orfordness in July 1930, from 2,000 and 4,000 feet, and all gave apparently satisfactory detonation below the surface, indicating that the bomb did not break on impact. The fragmentation trials took place place in September and, as far as could be judged, the new bomb was satisfactory.[2]

Delay, meanwhile had arisen in the production of the bomb bodies due to the fact that the anti-submarine bomb was of a composite type.

It had a reasonably strong nose to withstand impact, and thin walls to give maximum volume for filling. To achieve this the nose was cast or forged separately, and the body shaped from steel plate and welded; the nose and body were then welded together, and finally a strengthened tail closing plate was welded to the body. To strengthen up the thin cased body of the bomb two strengthening rings were welded inside, but not continuously. When the first production bomb was assembled in March 1930, it was inspected by the Inspector of Naval Ordnance (the bombs being entirely for the Fleet Air Arm) who raised the objection that the numerous joints created crevices inside the bomb into which the main filling must penetrate, and where it would be liable to squeezing and possibly to premature detonation. The Inspector at once suspended production pending an enquiry by C.S.R.D.

[1] A.M. File S. 24680.

[2] O.C. Memo. B. 21429/30.

C.S.R.D. recommended complete welding of the rings, followed by a coating of R.D. cement, but realising that this would mean a re-design of the rings, and would be a difficult process, he suggested as a reasonable alternative the continuance of spot welding with the application of pitch. This proved to be a long and tedious process and the use of shellac varnish instead was suggested by S. of D. After the necessary trials the use of R.D. cement was approved by C.I.N.O., and, on 4 July, the contractors received instructions to proceed with manufacture pending the preparation and issue of a fresh specification.

Various other manufacturing difficulties arose, particularly in the method of attaching the suspension lug which had to be strong enough to withstand a force of 5 g. in catapulting and the time was ripe for a new Mark III. Accordingly in September 1930, A.D.R.D. (Arm.) wrote to the Superintendent of Design asking for ' designs of a typical anti-submarine bomb in which the dimensions shall be approximately the same as in the present design, but in which the body will consist of either a straight taper, or else a combination of straight taper and short parallel portion . . .'

By November, S. of D. had submitted a proposed new design with a steel tail. This design was in fact not adopted. A further investigation into the alleged manufacturing difficulties, which had been connected chiefly with welding showed that they could easily be overcome by more careful application of welding heat. It is only fair to say that the difficulties of welding had been encountered mainly during the manufacture of experimental bombs by Woolwich, and not by the firms engaged in the production order.

The 100 lb. A.S. Bomb (Marks I and II) was finally introduced into service in March 1931, nearly six years after its conception by the Admiralty. It is significant that, up to that date, no trials to test the value of the bomb against the structure of a submarine had been made. And, still more lamentable, no scientific investigation of the bomb's behaviour under water had been organised. This was a matter of vital importance which does not appear to have been fully realised until the attack on enemy submarines again commenced nearly ten years later. During the following four years, no major advance in design was made although controversy arose at various times on such points as the amount of overweight which might be tolerated in manufacture, and the design of the suspension lug. In fact no effort was spared to make the exterior details of the bomb as perfect as possible.[1]

Before proceeding with the further history of the development of the bomb in its final Mark IV stage, it is necessary to trace the history of its two companions, the 250 lb. and the 500 lb. A.S. bombs.

The 250 lb. and 500 lb. A.S. bombs

The Admiralty had signified in a letter to the Air Council that they required only the 100 lb. bomb for use in the Fleet Air Arm. The Council, however, decided to proceed with the development of the two heavier bombs and designs were prepared by S. of D. on the lines of the new G.P. bomb and based on suggestions by D.D.R.(Arm.) The bomb was to have no central tube, a maximum explosive content consistent with strength of body to withstand impact on water from 4,000 feet, and a nose fuze. The filling was to be 80/20 Amatol, acceptable for R.A.F. use, but not for carriage in H.M. Ships.[2]

[1] A.M. File S. 24680.
[2] A.M. File S. 23954.

The designs were prepared, and were similar to those for the 100 lb. bomb already described, and by September 1927 four experimental bombs of each size were requisitioned from the Ordnance Factory at Woolwich for initial dropping trials. Since the original requirement for these bombs, the use of Baratol as a filling had been suggested by C.S.R.D. and two bombs of each size were filled with this explosive for trial. No special fuze for the bomb was ready, and an adapted shell fuze was modified to fit the bomb. The instructions to the Officer Commanding A. and A.E.E. on the subject of the trials are interesting, one paragraph reading :—

> 'As no bombing may take place over the sea at Orfordness during the months of November and December, it is an urgent necessity that the trial should be completed before the target is removed.'

The trials took place in October 1928 from heights of 1,000 and 5,000 feet and all bombs except one detonated satisfactorily.[1] (The failure of the one bomb was attributed to the fuze.) On the strength of this trial the bombs were judged suitable for production, and S. of D. asked to prepare a specification for manufacture.

In 1929, a new design of bomb was produced with a duralumin tail and with consequent modification to lighten the nose (this modification was applied also to the 100 lb. bomb and has been discussed at greater length above). At the same time Baratol was chosen as the standard filling for all bombs not intended for storage in ships. The original suspension lug was found to be unsatisfactory for use with the Universal bomb carrier, and this, too, was redesigned. The new design was given the designation Mark II.

Fragmentation trials to test the efficiency of the filling should then have been made at Shoeburyness, but the following two years were spent in spasmodic fuze trials which exhausted the small stocks of experimental bombs ; in arguments about the type of filling and in details of design of such parts as the suspension lug and the welding of the nose. In December 1931, further delay in development arose from a proposal by A.D.R.D.(Arm.) to revise and simplify the whole range of H.E. bombs and fuzes. This, in his words, ' would necessitate the redesign of A.S. bombs (to take both nose and tail fuze), in view of which it would be preferable not to proceed with the comparative detonation trials proposed in Ordnance Committee Memo. B. 23370.' The trials were finally cancelled in April 1935.[2]

The period is one of confusion and indecision during which small quantities of the existing Mark I and II continued to be produced, but in which no settled progressive policy was forthcoming. A.D.R.D.(Arm.) in his desire to reduce the number of types of bomb even went so far as to propose to A.M.S.R. that the 500 lb. S.A.P. bomb should be used as an anti-submarine bomb, provided a special fuze was used.[3] The project for reduction to one or two types disappeared with a change of A.D.R.D.(Arm.) in 1935, but further development of the bomb virtually ceased until 1934.

In that year A.D.R.D.(Arm.) approached the Ordnance Committee with an application to S. of D. to revise the design of the Anti-Submarine series ; the peculiar construction of the bomb case in three parts welded together, with

[1] A.M. File S. 23954.
[2] O.C. Memo. B. 28911/35.
[3] A.M. File S. 17413.

internal strengthening rings to reinforce the very light central portion had introduced various manufacturing difficulties which had been a constant source of trouble. Suspension lugs had been too weak to withstand the force of catapulting.

The new designs were complete by July, and about the same time the Air Staff was holding an investigation into reserves of bombs for a possible major war. The need for reserve supplies of A.S. bombs made it imperative that orders should be placed at once.[1] The new design was untried, but as it appeared a great improvement on the older designs, it was decided to place all future orders for the new design—Mark III.[2]

1934 is an important year in the history of the bomb, for it saw the beginning of an essential but belated series of experiments by R.A.E. to determine the underwater behaviour of the bomb. This investigation is intimately associated with the development of the special fuze designed for A.S. bombs, a history of which is given elsewhere in this Volume,[3] where the R.A.E. experiments are described in detail.

The Mark IV (solid nose) bomb

By 1936 it had become quite evident that the anti-submarine fuze (No. 32) was not only unreliable in action and disturbing in its effect on the path of the bomb under water, but, because of the complication of its mechanism, was extremely difficult to manufacture in the large quantities which it was anticipated would be required in war. At least 5,000 bombs were required to equip the Fleet Air Arm, and the Director of Naval Ordnance decided that something simpler would have to be designed, at any rate for the 100 lb. bomb, which was the chief Naval requirement. The trouble with the original bomb and its fuze was that too much had been asked of it. Already one of the requirements—variable delay setting from the cockpit—had been abandoned, but the others remained.

Members of the Ordnance Committee and representatives of A.D.R.D.(Arm.), Superintendent of Design and D.N.O. met in August 1936 and agreed that a simpler design of bomb and fuze, to meet the modified Admiralty requirements, could be evolved without difficulty.[4] These requirements were :—

(*a*) A fixed delay of about one second.

(*b*) No direct action.

(*c*) Safety.

(*d*) Arming (*i.e.*, becoming ' live ') in 200 feet.

(*e*) Must operate on water from height of 200 to 4,000 feet.

(*f*) Must be easy to manufacture.

(*g*) Must be simple and quick to prepare for use.

(*h*) Must be watertight.

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[1] The quantities required were minute compared with present standards :—

100 lb.	1,700
250 lb.	14,550
500 lb.	5,715

[2] A.M. File S. 35335.

[3] Chapter 17.

[4] A.M. File S. 39066/1.

This obviously meant a redesign of the bomb. The adverse effect on underwater path of the No. 32 fuze in the nose of the old bomb indicated that for improvement the contour of the nose must be continuous and the new fuze must therefore be fitted in the tail. The requirements for the new bomb were :—

(*a*) To have approximately 100 lb. weight.

(*b*) To be fitted with a snap-on tail and a tail fuze.[1]

(*c*) To be of good contour for underwater track.

(*d*) To have the largest possible explosive content consistent with strength to withstand impact on water from 4,000 feet.

(*e*) Should penetrate ¼ inch plate without breaking up (but this might be waived if it meant a serious reduction in the explosive content).

(*f*) To be capable of easy manufacture.

The design was described as one of the greatest urgency, and on 12 September the Ordnance Committee was requested to proceed on the highest possible priority with the new bomb and fuze. The Superintendent of Design wasted no time, and within a month had produced a design to meet the requirements.

The design was sent to R.A.E. for comment on stability in air and water, and after all necessary tests R.A.E. reported favourably on the design, and twenty bombs were manufactured by the Ordnance Factory for trial. By March 1937, nine of these were ready, and were sent to A.A.E.E. for test. Three with inert filling were to be dropped on water from 4,000 feet, at Shoeburyness for recovery, and were fitted with dummy detonators with live caps ; three filled H.E. with one second detonators to be dropped at Orfordness from 500 feet and three from 4,000 feet. The trials were completed in June and July. The live bombs failed completely, due to faulty pistol design. A.D.R.D.(Arm.) considered this design so likely to give failure that S. of D. was asked to prepare an entirely new design on the lines of the G.P. Mark IV bomb, and also to prepare similar designs for the 250 and 500 lb. A.S. bombs, and the contractor agreed to manufacture twenty of each.

Four 100 lb. and four 250 lb. bombs were ready for trial in December ; one of each failed, and in further trials in January a third bomb failed. The sensitivity of the detonators was suspected, and in trials with a more sensitive type in April 1938 two bombs failed from 500 feet.

The design of the pistol was then suspected, and S. of D. carried out modifications to the striker pellet to eliminate possible jamming. Trials in June again resulted in the failure of one bomb. A sharpened striker and sensitive detonator were then tried, and trials of twenty-two bombs (100, 250 and 500 lb.) from 500 and 4,000 feet were completely successful. In October, arrangements were made for the immediate production of fifty of each size of bomb, now given the title Mark IV.[2]

The charge/weight ratio of the new Mark was virtually identical with the older nose-fuzed types. Ballistics in air were satisfactory, and although no underwater tests had been made, the shape corresponded to that stipulated by R.A.E. The main filling of the new bomb was T.N.T. although later an alternative filling of a mixture of T.N.T. and R.D.X. was used.

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[1] A principle then being applied to all G.P. and similar bombs.

[2] A.M. File S. 39066/1.

Fuzing arrangements for the Mark IV bomb

Although production orders for the new bomb had been placed, trials of the fuzing system were continued. The pistol originally used was the standard blunt striker pistol for small H.E. bombs equipped with clip-on tails, and used in conjunction with an anvil type detonator having a delay of one second. This combination had been unsuccessful and had been replaced by a modified pistol having a sharpened striker (No. 30) and a sensitive type detonator. Trials of this combination in September 1938 had been successful, but for confirmation further trials were made by A.A.E.E. in November. The same trial was employed to establish the strength of the clip-on tail, which was a feature of the new bomb—as of the majority of H.E. bombs at that time. The 250 lb. and 500 lb. bombs released from 500 and 4,000 feet were entirely successful. The test of the tail was drastic as a Harrow aircraft was used, in which the falling bombs had the task of opening the bomb doors. Although the tails proved satisfactory the conclusion was that they were somewhat flimsy for the rough and tumble of aerodrome handling, and a heavier gauge was recommended. Subject to this modification, the Ordnance Committee recommended in December 1938 that the design for the new bomb and fuzing should be approved. They suggested that drops from 500 feet from a Blenheim or other fast aircraft should be made to test the bomb's behaviour with a flat angle of entry.

By May 1939, the initial order for fifty bombs of each size had been completed, and the bombs filled at Woolwich, a quantity being sent to Martlesham and Felixstowe for dropping trials. Drops from 4,000 feet to test delay and from 500 feet to test flat entry were arranged, those bombs sent to Felixstowe were to be taxied on water before dropping. Unfortunately, of the first four bombs dropped from 4,000 feet by M.A.E.E. only one was satisfactory, the others having delays so short that they could not be recorded. Further trials were suspended and the suspected detonators sent to the Chief Inspector of Armament at Woolwich for examination. Detonators were borrowed from Admiralty stock to continue the trials.[1]

The taxying trials were delayed until May 1940, partly through the move of M.A.E.E. from Felixstowe to Helensburgh and partly through the inability of the Establishment to obtain the necessary pistols and detonators. After severe drenching, the fuzing system was found to be dry inside, and the probability of the effectiveness of a bomb being impaired through entrance of moisture was considered remote.[2]

The first four months of 1940 were spent in an investigation into frequent failures of the Mark IV bomb experienced by the Fleet Air Arm, who had by that time considerable experience with the 100 lb. model, and the Admiralty organised extensive trials at Lee-on-Solent. Although no definite cause of failure could be established, some conclusions were drawn; the number of failures of the No. 30 pistol were estimated at 40 per cent.; the inference was, that the high speed of rotation of the spindle was a contributory cause; the arming vane and spindle were seen to vibrate excessively. Modifications to the pistol, designed by the Naval officers conducting the trials (the arming vane nut was steadied by light leaf springs, which held it in position clear of the threads, in the armed position), reduced the percentage of failures, and a liberal application of grease on the arming vane spindle also assisted in this.[3]

[1] A.M. File S. 39066/2.
[2] A.M. File S. 39066/3.
[3] A.M. File 756870/38.

Coarsening of the pitch of the arming vanes also gave improved performance, and a continuation of these measures gave no failures in the bombs dropped. Instructions were therefore sent to all ships carrying aircraft ordering the modification to be made to all pistols held. Members of the Ordnance Board and representatives from the Admiralty met at Boscombe Down in late February to discuss the forthcoming trials, and decided that drops on land would yield no useful information ; and water trials at Lee-on-Solent were organised instead.

Meanwhile modified arming nut assemblies were hurriedly manufactured and sent on to all R.A.F. units holding Mark IV bombs. Trials made by A. & A.E.E., in Lyme Bay in April, with a simple modification suggested by the Ordnance Board, gave satisfactory results. A. & A.E.E. however suggested further modifications to the pistols. These were incorporated and a further fifty releases, asked for by the Ordnance Board, and completed by the end of April, were completely successful.[1]

No further major development to the bomb or its components was made, although it came under a certain amount of suspicion during 1943 at home and later in 1945 in Australia, of premature detonation. As a bomb it shared the same disadvantage as the earlier Marks in failing to meet the requirements formulated by the Anti-Submarine Warfare Committee in July 1941 ; that for the successful attack of submarines, detonation must occur at 20 feet depth, and that for accuracy of attack, aircraft must bomb from 50 feet or less (until an efficient low level sight could be designed). For these reasons the anti-submarine bomb was virtually abandoned after 1940 in favour of the depth charge with its hydrostatic pistol.

Later types of A.S. bombs : Development 1939–1945

At the outbreak of war the bombs available for the attack of enemy submarines were those described in the foregoing account, of doubtful quality and untried in operations. Very shortly after the beginning of the anti-submarine campaign it became clear that none of these bombs was satisfactory : grave doubts were cast on their efficiency and the No. 32 fuze was unreliable. Moreover the under-water path of the bombs was unpredictable, particularly when released from low altitudes, and, because of the small lethal range of the charge, extremely accurate bombing was essential. Such accuracy was difficult to achieve and no reliable low level sight then existed. It was therefore necessary to bomb from an extremely low height, and for this the bombs were not only unsuitable, but possibly dangerous.

It was therefore necessary to look round for a new weapon, the immediate substitute being the Naval Depth Charge, a weapon of very high charge/weight ratio, and, because it relied on a hydrostatic fuze and not an impact pistol, a safe weapon for the aircraft to release from 50 feet or less. This safety was not bought entirely without cost, for a direct hit on a submarine would not detonate the charge, it was hoped however that the depth charge would roll off and detonate immediately below.

For the first two years of War the depth charge—modified for air use—remained the standard weapon of the R.A.F. for anti-submarine attack, during which time the whole subject of weapons and means of attack was constantly under review by the Anti-Submarine Warfare Committee (Admiralty) in

[1] A.M. File S. 39066/3.

conjunction with Coastal Command. The deliberations and decisions of these authorities concerned improvements to, and the use of, depth charges, and are referred to in Chapter 5. It is appropriate now to turn to the later types of anti-submarine bombs developed from 1942 onwards, *i.e.*, the 600 lb., 35 lb. and 250 lb. Marks V and VI types, the history of these following in that order.

The 600 lb. A.S. bomb

On 31 March 1942, the C.-in-C. Coastal Command wrote to the Air Ministry (A.C.A.S.(T)) in the following terms :—

> 'For the entire duration of the war, to date, we have been attempting to attack U-boats with two types of depth charge, neither of which is capable of giving satisfactory results. We started off with the standard Admiralty D.C. and have made many attempts to make it a satisfactory aircraft weapon. Despite all attempts to improve it, it has now been found impossible to clear the Mark VII D.C. for heights above 150 feet and speed above 150 knots.'

He then went on to describe the smaller Mark VIII 250 lb. D.C., specially designed for F.A.A. and Coastal Command aircraft incapable of carrying the larger Mark VII (particularly the Hudson).

> 'This weapon has been more satisfactory from the point of view of tactical use since it is not restricted in height and speed . . . but its killing power is quite inadequate and is seriously impeding the effect of our anti-submarine warfare as a whole.
>
> We therefore require that a special aircraft depth charge should be developed on the highest priority and to the following specification :—
>
> 1. Total weight not to exceed 500 lb.
> 2. Highest possible c/w ratio.
> 3. Torpex filling.
> 4. Must be capable of being dropped from heights up to 5,000 feet and speeds up to 200 knots.
> 5. The pistol to be so arranged that it is not affected by cavitation, and should therefore operate at a depth of 25 feet.
> 6. The maximum diameter should not exceed 12·9 inches.
> 7. Shape to reduce cavitation to a minimum.
> 8. Constant trajectory.'

The proposal was reviewed by D.O.R. who replied on 7 May that D.Arm.D. had been asked to develop on high priority a weapon to satisfy the Command's requirements. The delay in this reply, was due to the necessity for an examination of all 500 lb. stowages in all aircraft likely to carry the new weapon.[1]

The Coastal Command specifications for the proposed bomb were meanwhile revised by D.O.R. and forwarded to D.Arm.D. The formulated requirements were :—

Weight	600 to 650 lb.
Maximum length	72 inches*
Maximum diameter	18 inches

Nose and tail fairings to be arranged so that they left the body of the bomb on entry.

[1] A.M. File C.S. 14212.

Detailed requirements for the fuze were added :—

> It was to be hydrostatic and variable between 20 and 150 feet depth. It should be fitted with a device, operated by the pilot, to increase automatically the smaller depth limit at the rate of 2 feet per second.

If this rather complicated requirement would cause prolonged delay in production, two fuzes, one set at 25 feet and the other at 50 feet would be used. Further, so that the bomb might be available immediately the cases were manufactured, it was to accommodate at the beginning a hydrostatic fuze already under design for the existing A.S. bomb, to detonate at 25 feet. The filling was to be Torpex or Minol.

Air Staff and D.Arm.D. had responded quickly to Coastal Command's request, but to make sure that he was not embarking on a false trail, D.Arm.D., after all preliminary work had been done, consulted the Weapons Sub-Committee of the D.A.S.W.[1] Anti-Submarine Warfare Committee, and asked for comments on the new project.

The Committee confined its comments to the value of the new bomb as a replacement for the 450 lb. depth charge, then the standard anti-submarine weapon.[2] In their deliberations they were guided by a Report made by the Standing Committee on A.S. Warfare in March 1942. This paragraph is so important that it may profitably be quoted here. It deals with the optimum size of non-contact bombs.

> 'One can define a requisite lethal stick length of bombs equal to four times the bombing error for range. With small non-contact bombs one can produce a longer lethal stick than with the same weight of big non-contact bombs. For small aircraft which cannot carry the requisite stick length of any kind of bomb, it pays to use the smallest non-contact bomb. For very large aircraft which can carry the requisite stick length of the biggest non-contact bombs it pays to carry the biggest sizes since in practice these have the important advantages of producing proportionately more internal damage to U-boats, requiring less critical depth settings and stick spacings and affording a greater vertical zone of lethality than small non-contact bombs. From this one can conclude that the most effective of all single attacks is that obtained with a very large aircraft dropping the requisite stick length of very large bombs—but this of course is not the most economical load.'

After discussion the Committee concluded that the proposed 600 lb. bomb had the following advantages over the 450 lb. depth charge :—

(*a*) Higher charge/weight ratio.

(*b*) Improved depth setting.

(*c*) Less operational restriction.[3]

Of these they considered (*b*) to be the most important, and as extensive work on the improvement of the Depth Charge pistol was then in progress, if this were successful there would be little to choose between bomb and Depth Charge. In fact the Committee's opinion was that—'given satisfactory depth settings, there is little to choose between any kind of bomb from 250 to 650 lb.'

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[1] Director of Anti-submarine Warfare—Admiralty.

[2] M.A.P. File S.B. 37551/1.

[3] The Naval depth charge would not stand dropping from more than a few hundred feet.

Meanwhile the revised requirements for the new bomb formulated by D.Arm.D. had been examined by Coastal Command who were not entirely satisfied. The Command had originally asked for a bomb which could be released from up to 10,000 feet. D.Arm.D. cut this down to 1,500 feet, so that the minimum case thickness and the maximum charge/weight ratio could be obtained. The Command now asked for a compromise of 5,000 feet, to which D.O.R. and D.Arm.D. agreed.[1]

Coastal Command's original request had been dated 31 March. In June the C.-in-C. approached D.O.R. for information of progress, asking for the bombs with the least possible delay. D.Arm.D. was able to report at the end of June that the design was nearing completion following which models would be made for tank trials at R.A.E.[2] He promised development ' at the utmost speed '. Two days later, however, in a discussion with O.R.2, D.D.Arm.D.(B) stated that it was unlikely that any new bombs would be available for at least nine months. From this time until the end of 1942, when the bomb was still unavailable for operational use, the C.-in-C. Coastal Command was obliged to write letter after letter to Air Ministry asking for haste in the development of the weapon, or in the production of Torpex for its filling.

We return now to the details of development. C.S.A.D. produced a sketch design in June 1942, a copy of which was sent to R.A.E. so that models for underwater trials might be made. Information was asked for on depth-time relationship, shape of trajectory, attitude, and cavity phenomena for an entry speed of 350 feet per second and angles of entry between 10 and 45 degrees to the horizontal. Meanwhile the manufacture of the first bombs for trial was undertaken and break-off tails were made on the lines of those of the ' B ' bomb.[3]

An original order for twelve bombs, followed shortly afterwards by an order for thirty-six more, was made. By August, after hastening action by the C.-in-C. Coastal Command, these original bombs had not been completed, and instructions were given for the highest priority in their manufacture. To hasten this the two fuze positions were to be omitted, and one exploder, contained in the tail, only included. Meanwhile, the Torpedo Development Section at Gosport had received instructions for initial dropping trials immediately bomb bodies became available. These were to include observation on the behaviour of the break-away nose and tail, and air ballistics, and were to be made at the Unit's sea range at Weston-super-Mare. By 30 July, initial model trials at R.A.E. had been completed. Violent pitch and yaw had been observed, and in some cases the bomb somersaulted. Such behaviour made accurate and safe hydrostatic fuzing impossible at small depths.

By 20 August, the Torpedo Development Unit trials had been completed. Twelve bombs were dropped from heights of 50 to 3,000 feet ; air ballistics were good. Noses and tails broke away satisfactorily on impact and not in the air, also, so far as could be observed, the bombs were not damaged by impact. Towards the end of August arrangements were made for trials to determine the depth of detonation from various heights, and to confirm that the bomb might be jettisoned safe. These were to be undertaken by M.A.E.E. at Helensburgh.

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[1] A.M. File C.S. 14212/1.
[2] A.M. File C.S. 14212.
[3] M.A.P. File S.B. 37551.

The Helensburgh Report is dated 23 September 1942. The eighteen bombs allotted for trial were received on the 8th of this month and little time was wasted. Four bombs with fuzes set to fire at 30 feet were dropped from a Sunderland, two from 50 and two from 250 feet, at 150 knots. Bombs were stable in air, nose cap came away on impact and there were no ricochets. The bombs at 50 feet failed to fire owing to a fault in the fuze: the others fired at 42 and 66 feet but these results were found to be worthless as the priming hole in the C.E. magazine had not been closed.

Further trials with specially prepared fuzes gave detonation at 38, 40, 27 and 30 feet—average 34 feet. Various minor faults in the design of the fuzing arrangements were discovered. Still further trials in late September were made with fuzes accurately calibrated by C.S.A.D. and from heights of 500 feet and under, giving firing depths from 22 to 42 feet.

It was thus evident that there was wide variation in the firing depth, and this was attributed by M.A.E.E. mainly to variation in the height of release. They gave as their opinion that the variation was due to differences in the time of persistence of the cavity formed by the bomb entering the water at a relatively steep angle. From the greater heights the cavity persisted to a greater depth than the fuze setting (20 feet). Bombs entering at shallow angles remained near the surface during the cavity stage and then sank slowly to firing depth. As a result of these various trials, which had shown that the bomb case was satisfactory, an order for 500 was placed in October 1942, and in response to a War Cabinet ruling, 50 bombs were to be ready for operational use by the first week in November.[1]

Meanwhile a controversy had arisen on the question of H.E. filling. The original requirement had been for the best procurable explosive for underwater disruption: and the best known explosive was Torpex containing R.D.X., then still a rare product. At the D.A.S.W. meeting on 9 September, it was made clear that Torpex for the new bomb would not be available, as the majority of available supplies was needed for the Army and Navy.[2] This brought a strong protest from the C.-in-C. Coastal Command, Sir Philip Joubert, addressed to Sir Henry Tizard, Scientific Adviser to the Air Ministry, with copies of his letter to the S. of S. for Air, and A.C.A.S.(T). At the same time he sent a demi-official letter to A.C.A.S.(T) in similar terms.

To Sir Henry Tizard he explained that the new 600 lb. bomb was required as a replacement for the 250 lb. depth charge, which had been proved to be ineffective unless practically a direct hit were obtained. With any other filling except Torpex, or an equivalent explosive, no advance would, in the C.-in-C.'s opinion, be made.

To A.C.A.S.(T) he claimed that with a less disruptive filling than Torpex the whole object of the heavier bomb would be defeated. The carriage of a heavier bomb reduced the length of the stick, to compensate for which a more efficient explosive was needed. With a T.N.T. or Amatol filling he claimed that

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[1] M.A.P. File S.B. 37551/2.

[2] Allocation of R.D.X. .. .. July to December 1942.

First Priority	Torpedo Heads; 250 lb. Depth Charge; 100 lb. A/S Bombs.
Second Priority	Army.
Third Priority	Balance to R.A.F. for 8,000 lb. H.C. and 500 lb. M.C. (Amatex).

the 600 lb. A.S. bomb would be half as effective again as the 250 lb. depth charge, whereas with a Torpex filling it would be three times as effective. Even if Torpex added but a few feet to the lethal range, these few feet were critical in A.S. attacks. Failing Torpex, on which however he insisted even at the expense of all other requirements, he asked for Minol or Amatex.

To this A.C.A.S.(T) replied, on the advice of D.O.R., that Minol 2 would be used, and that the Ministry of Supply had undertaken to provide fifteen tons of aluminium powder for the manufacture of enough filling for the development order of one thousand bombs.[1] The first fifty bombs were available for service by the beginning of November 1942, but several essential trials were still in progress or outstanding; safety in jettison was not yet established, and no live drops had been made; neither was it certain that the hydrostatic fuze (No. 862) would not fire on impact, nor that countermining would not occur. Nevertheless, as the C.-in-C. Coastal Command continued to press for more and more intensive development, a production order for one thousand was madé in the hope that these essential trials would be successful, and so that manufacture could proceed concurrently with trials. Further, owing to the great pressure applied by the C.-in-C. many faulty components were being turned out and had to be rejected.[2] Thus, though the bomb was in a sense ready for service use by 1 November in accordance with the War Cabinet demand, it was in fact not yet in a state for dropping against U-boats with a full sense of security for the aircraft or a reasonable certainty of success.

By the end of October, inert dropping trials had been completed by the Torpedo Development Unit. Eight bombs out of ten were recovered, having been dropped from a Beaufort fuzed 'safe' from heights of 1,500 to 50 feet in 30 feet of water. All recovered bombs were found in the 'safe' condition, and the safety of the bomb when jettisoned was thought to be established.

Live and inert drops were made by M.A.E.E. in November. In the former four failures occurred out of six bombs dropped from 1,500 feet: two out of four from 1,000 feet: no failures occurred from 750 feet. Some damage was done to the aircraft from bombs accidentally dropped in salvo from 750 feet, when detonation was thought to have occurred at under 30 feet. No tendency to premature detonation was observed but 'venting' through the cavity caused by the entry of the bomb—that is to say, blast upwards and unimpeded by water—was noticeable when detonation occurred at less than 30 feet, and M.A.E.E. recommended tests to determine minimum safety height for dropping, particularly in sticks. In the inert trials—held to assess the underwater behaviour of bomb and fuze—the results were very satisfactory, forward travel and depth of detonation being consistent and sideways deviation of track very slight.

The position by mid-December 1942 was that, while bombs were being produced at the rate of some fifty each week, and were being distributed to Coastal Command Stations, D.Arm.D. still withheld his authority to drop the bombs other than singly, until countermining trials should have been completed and the safety of dropping aircraft established. These trials commenced at M.A.E.E. on 10 December, when, in conjunction with the Naval Establishment at Arrochar, inert-filled bombs with live exploders and fuzes were suspended at various distances under water from an H.E.-filled bomb.

[1] A.M. File C.S. 14212.
[2] M.A.P. File S.B. 37551/2.

Countermining occurred at distances up to 70, 80, and 90 feet; at distances up to 70 feet the inert bombs were badly damaged, and it was evident that further trials were necessary to establish the minimum safe spacing at which the bombs could be dropped. Air trials a few days later showed that the bomb was safe to aircraft dropping sticks of two bombs only from 50 to 100 feet at 200 m.p.h., with spacing of 60 to 90 feet, and clearance was given to Coastal Command to use the bomb under these conditions.

Meanwhile at D.Arm.D.'s request the problem of countermining had been put to C.E.A.D. who promised to design an anti-countermining device for attachment to the fuze. By the end of the month he had produced two types—one with a ball and one with a button valve—which were sent at the beginning of January to M.A.E.E. for trial. Trials of the button valve type were unsuccessful: the ball valve was somewhat more successful and only one bomb out of five countermined. A third device was tried, consisting of an air chamber surrounding the fuze, but again was only partially successful.[1]

Impatience in the delay of full operational clearance had meanwhile brought yet another letter of protest from the C.-in-C. Coastal Command, who wrote to the Air Ministry on 28 December, to complain that a year had elapsed since he asked for the 600 lb. bomb (his original letter was in fact dated 31 March 1942) and that in spite of 'encouragement to hope that by winter we should possess this weapon', the 600 lb. A.S. bomb was not yet passed as satisfactory. He asked that the fuze should be cleared as quickly as possible against countermining, and that it should be tried from 4,000 feet against a ship target. This latter request was a new one and had never appeared in any Coastal Command requirement, although the C.-in-C. claimed that it had always been implied.[2]

A.C.A.S.(T) expressed surprise—not without reason—at this letter, in view of the fact that the C.-in-C. was in constant touch with progress through the U-boat Committee, and must be aware that its development was on the highest level of priority.

D.O.R. replied in these terms to the C.-in-C., pointing out that as the Anti-submarine Warfare Committee met regularly at Headquarters Coastal Command under his chairmanship, he should be fully aware of the position. He pointed out that the bomb was obviously unsuited for the attack of surface ships as it had a hydrostatic fuze, and was in any case not strong enough to penetrate either deck or hull—another fact which had been well known from the beginning. He then pointed out that such a dual-purpose weapon as that proposed by the C.-in-C. would not only complicate design but would reduce the efficiency of the bomb as an anti-submarine weapon—its primary function.[3]

The period between January and April 1943 is one of some confusion in the development of the bomb and fuze. Trials of fuzes with various modifications continued at Helensburgh (M.A.E.E.) and the services of H.M.S. *Vernon* (Torpedo and Mine Research) were enlisted in an examination of the under-water behaviour of bomb and fuze.[4] By the end of March, D.Arm.D. was able to inform Coastal Command that the bomb might now be dropped singly or in sticks with a spacing of 80 feet or more, and from heights between 1,200 and 5,000 feet at any speed.[5]

[1] M.A.P. File S.B. 37551/3.
[2] A.M. File C.S. 14212.
[3] M.A.P. File S.B. 17360.
[4] M.A.E.E. Reports H.Arm.88D, E and F: H.Arm.95.
[5] M.A.P. File S.B. 37551/5.

This was well enough, but the low limit of 1,200 feet was unsatisfactory, particularly as the Mark III low level bombsight was by then in service. As there seemed little likelihood of the fuze designed originally for the bomb satisfying the demand for low level attacks, efforts were made to use the Depth Charge Pistol Mark XIV, pending the development of a really satisfactory hydrostatic fuze. Pistols had been set to fire at 27 and 18 feet, but the firing depths when the pistol was used in the bomb were very erratic, and often too shallow to allow for safety to the releasing aircraft. M.A.E.E. therefore recommended that its use should be abandoned.[1]

By May, R.A.E. had produced another design of anti-countermining valve, which, in conjunction with an air chamber round the fuze, was tried at M.A.E.E. in that month.[2] The principle of these devices was simple enough: the chamber—a simple metal sleeve surrounding the fuze, with water inlets at the top—prevented the fuze from damage by under-water blast, and restricted the flow of water to the fuze so that the chamber did not completely fill during the early stages of descent. The valve was designed to close rapidly when any sudden shock wave was encountered, such as that caused by another bomb detonating in the vicinity. The primary object of the trial was to test the effect of these additions on detonation depth. Bombs dropped from 50 feet were satisfactory but the results from those dropped from 500 feet were inconclusive with indications that depth of detonation was slightly increased by the modification to the fuze. This trial was followed immediately by a static trial for countermining with the same modification, by H.M.S. *Vernon*: a 600 lb. bomb was detonated at 30 feet, with two inert filled bombs 80 feet away, at 10 feet depth. In two trials the fuzes did not countermine, and it appeared as if the R.A.E. valve had solved the trouble.

As a result of these trials, and of calculations by C.S.A.R., the bomb was cleared for dropping from 500 feet and over with a spacing of 120 feet. Few cases of countermining at this spacing were to be expected, and even if they occurred would entail no risk to the aircraft. They would however decrease the efficiency of any bomb detonated by countermining too near the surface. This safe minimum of 500 feet was confirmed by trial at M.A.E.E. on 6 May, when five sticks of two Minol filled bombs were dropped from this altitude without danger to the aircraft. Some countermining occurred, but the fuzes used were unmodified and this was to be expected. On 5 June 1943, the 600 lb. A.S. bomb was formally introduced into service by A.C.A.S.(T.R.) with the qualification that it was subject to further improvement, and that development must continue.[3]

Although the bomb was now regularly in service use by Coastal Command, there was still a height limit to its use: and trials continued during June 1943, in an effort to reduce the low limit of 500 feet. In this month sticks of two and three bombs with modified fuzes R.A.E. valve and air chamber were dropped by M.A.E.E. from heights of 250 and 100 feet. At the former height the trials showed that countermining was generally cured by the device: at the lower height severe countermining occurred and in one stick of three, all detonated together, the detonation shock being passed from one to the other. In spite of this, and the fact that the last bomb detonated at some 16 feet below the surface, no blast or fragment damage was caused to the aircraft: some damage

[1] M.A.P. File S.B. 37551.
[2] M.A.P. File S.B. 37551/6.
[3] A.M. File C.S. 14212.

did however occur from parts of the break-away nose fairing which were thrown up on impact or detonation. During the 100 feet trials failures occurred and it was surmised that fuzes were damaged by under-water shock. It was concluded, therefore, that provided the failures could be reliably diagnosed and cured, the bomb could be cleared for heights down to 100 feet, but that further confirmatory trials were advisable.

These were completed by the end of June: no countermining occurred in nine sticks of three bombs from 250 feet, but at 100 feet it occurred in four sticks out of five: in one case shock but no damage was felt in the aircraft. As a result, D.Arm.D. decided in July, that 100 feet might be laid down as the minimum dropping height, and that even if aircraft inadvertently came lower the risk of damage was slight and acceptable. The limits of the bomb were henceforth: heights 100 to 2,000 feet: stick spacing (three bombs) 120 feet. (The number of bombs per stick was increased to four the following month.)[1]

By August 1943, a total of four hundred experimental bombs had been dropped—all under trial and observation conditions—a remarkable achievement. It may be of interest to analyse the trials carried out with the Mark II (air chamber and valve) fuze, which had then become the standard operational fuze: one hundred and fifty-seven bombs fitted with this fuze were dropped. The total number of failures to detonate was nine ($5\frac{1}{2}$ per cent.), a great improvement on the earlier fuze where the failure rate was 10 per cent. The fuze setting in all cases was 27 feet, and the mean firing depth measured for eighty-five bombs was also 27 feet: the depth of detonation error for 50 per cent. of all bombs recorded was plus or minus 3·6 feet.[2]

Although the bomb had been in operational use for some months it still did not entirely fulfil the original requirements; its height limitation was 2,000 feet over which fuze failure occurred. Fuze development between August 1943, and December 1944, was concentrated on efforts to improve this height limitation, and resulted in the introduction of the No. 895 fuze to replace the No. 862, giving much wider scope in the use of the bomb as the following figures show:—

Height	50 to 5,000 feet.
Stick spacing	Minimum 80 feet.
Air speed	250 knots.
Firing depth: mean ..	32 feet.

It will be noticed that from November 1942, when the first filled bombs were ready for Coastal Command, all further development was connected with the fuze: the bomb remained in its original form (Mark I) throughout its service life.

According to Coastal Command statistics a total of ninety-seven 600 lb. bombs was used in twenty-eight attacks on submarines between May 1943, and April 1945. Many factors must have contributed towards this seemingly insignificant use of the bomb as compared with, say, the figures for the 250 lb. depth charge in exactly double the time, 1,170 attacks with 5,790 charges dropped. It is true that for the greater part of its operational life fuze problems imposed a tactical restriction on the use of the bomb, e.g., height from 100 feet to 2,000 feet, but similar restrictions were applied when using depth charges, and it does appear that there was bias of some sort against the use of a weapon asked for to improve upon or replace the depth charge.

[1] M.A.P. File S.B. 37551/7.
[2] Analysis of various M.A.E.E. reports.

The 35 lb. A.S. bomb

At the beginning of 1942, experiments were being carried out by M.D.1[1] with what were known as hollow or shaped charge explosives. Very briefly the hollow charge is a mass of High Explosive of roughly hemispherical shape, the flat side being hollowed out conically : the increased surface area so obtained directing the detonation wave towards the mouth of the cone like the beam of a car headlight. The concentrated detonation wave or jet so formed has very high penetration qualities against armour plate. It was thought that the hollow charge would be particularly useful in holing the pressure hull of a U-boat.

On 27 August 1941, the German submarine *Graf* (*U-4570*)[2] was captured intact by a Hudson aircraft of No. 269 Squadron, Coastal Command, and brought to England. Plates representing various parts of her structure were prepared and between January and April 1942, a number of trials with hollow charges of some 5 lb. of H.E. were made against these targets, with what the Ordnance Board described as ' promising results '.[3]

On 18 May 1942, the Weapons Sub-Committee of D.A.S.W.'s Anti-submarine Warfare Committee met under the Chairmanship of Professor Blackett, Scientific Adviser to the Board of Admiralty, to discuss a design for a small hollow charge bomb for U-boat attack. The meeting was attended by representatives from Coastal Command and four Directorates of the Admiralty—Scientific Research, Miscellaneous Weapons, Air Division, and Anti-submarine Warfare.[4]

The committee considered the comparative merits of a 100 lb. A.S. bomb and a small hollow charge bomb containing 12 lb. H.E., with a total weight of 35 to 40 lb., from every aspect, but were unable to come to any firm conclusion, except that for light carrier-borne aircraft a number of small bombs rather than one large one would be desirable.

The committee requested further evidence before making a firm assessment and concluded that the evidence available to date did not justify a staff requirement, but did justify the design of a bomb by D.Arm.D. having a hollow charge of 12 lb. with a 0·16 inch steel cone and a diameter of 8 inches. The bomb should be stable in air and water and should withstand impact with water at 200 knots from 150 feet. Early in June, a further assessment was made in which the conclusions reached were in the main unfavourable to the proposed bomb (weight about 30 lb.) although the Committee's recommendation was that further research should be directed towards obtaining a bomb of similar performance at about 20 lb. weight, with a suitable fuze.

From this very brief summary it will be seen that the hollow charge bomb was, at least, of doubtful value. On 24 June 1942, D.Arm.D.'s deputy D.D.Arm.D.(Bombs) pointed out that such a bomb would be difficult and uneconomical in stowage in, or carriage under aircraft, and that the assessment of the Weapons Sub-Committee showed that there was no real case for the bomb. D.O.R. recommended to A.C.A.S.(T) that no more time should be wasted on the weapon, and A.C.A.S.(T) ruled that there was no Air Staff requirement for it.

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[1] A Directorate under the Minister of Defence (*i.e.*, the Prime Minister).

[2] Re-named H.M.S. *Graph*.

[3] A very full report of these trials is contained in Appendices to O.B. Proc. Q.544.

[4] A.M. File C.S. 15474.

In the meantime Admiral Usborne had got M.D.1 to make up six hollow charge bombs with 12 lb. H.E. charge which were tested against underwater targets representing sections of a submarine, by the Director of Miscellaneous Weapons, Admiralty, in collaboration with M.D.1.[1] These trials met with some success, and on the strength of these results, D.O.R. was prepared to keep an open mind on the value of the bomb, and in August recommended, to A.C.A.S.(T), that no action should be taken in favour of or against development until all new facts had been examined.[2] In October, a formal request was forwarded by the Admiralty to the Minister of Aircraft Production for the collaboration of his Technical Staff in the development and trials of the bomb, and its stowage in aircraft.[3]

Preliminary air trials were completed by D.M.W.D. at Weston-super-Mare on 21 October 1942, when ten inert bombs were released from a Manchester aircraft. The air ballistics of the bomb were good but strengthening of various parts was found to be essential to withstand impact on water. Further trials with strengthened bombs were made at the end of the month from 50 and 500 feet with more successful results, but weakness in the tail portion of the bomb was still evident.

During the same month a meeting under the chairmanship of D.M.W.D. was held to discuss the programme of development. Here it was agreed that D.M.W.D., D.Arm.D. and D.M.D.1 should continue to collaborate on trials, under the direction of D.M.W.D. should the design appear sufficiently promising to merit an Air Staff requirement, D.Arm.D. would take over this direction.

In November the new bomb was discussed by the Weapons Sub-Committee with a view, if possible, to recommending the laying down of a Naval Staff requirement for the bomb for carriage in Swordfish, which were at a great disadvantage when taking off in low winds from auxiliary carriers with their normal load of from 250 lb. depth charges.

After a very careful examination of all available data the Committee unanimously decided that 'with the information at present at their disposal they could not recommend the 30 lb. shaped charge bomb as an alternative to the 100 lb. A.S. bomb.' This conclusion was based on the following main arguments :—

(*a*) The fuze of the shaped charge bomb will not fire when it strikes a plate at an angle of less than 30 degrees between the axis of the bomb and the plate.

(*b*) The bomb will not be lethal when the angle to the pressure hull is greater than 45 degrees and the distance from the pressure hull is over 48 inches.

(*c*) Angles of attack greater than 45 degrees from the beam cannot be successful as owing to the striking angle the bomb cannot be lethal. This completely rules out up-track attacks.

Nevertheless the War Cabinet Committee decided that development of the shaped-charge bomb must go on, and instructed M.A.P. to order two thousand bombs as soon as the Admiralty and Air Ministry were able to produce a satisfactory design. By this time D.M.D.1 had produced a sketch of an alternative

[1] O.B. Proc. Q.652. 12 August 1942.
[2] A.M. File C.S. 15474.
[3] M.A.P. File S.B. 36570/1.

design to that already tried. This included modification to the cone angle (60 degrees instead of 80) an increase of charge of about 3 lb., and some changes in body design.[1]

Development of the bomb was still in the hands of the Director of Miscellaneous Weapons and M.D.1, and in view of the Cabinet Committee's decision, D.M.W.D. called a meeting of various members of his staff, together with D.D.O.R., D.D.Arm.D. (Bombs), and Brigadier Jeffris, who had long been concerned with the design of shaped charge weapons. The meeting agreed that development work should proceed.

On 26 November 1942, both Admiralty and Air Ministry had decided that the bomb was promising enough to be made an operational requirement. By the middle of December, drawings of the latest design of bomb and fuze had been sent by D.M.D.1, D.M.W.D., and D.Arm.D., and twenty-four bombs were ready for trial.[2]

D.Arm.D. in co-operation with the Ordnance Board and representatives of D.M.W.D., C.E.A.D., and M. of S., drew up on 18 December a schedule of acceptance trials, to include static firing with various thicknesses of cone, and a filling of R.D.X./T.N.T. ; air ballistics, water entry and strength on impact from 50 and 250 feet ; under-water path down to 40 feet ; release and jostling trials. A programme of fuze trials included ability to withstand impact, premature firing, distance to arm, effect on plate and wooden decking at various angles of impact, at medium and high velocity—the latter obtained by firing from a gun—sealing, safety, rough usage, detonation at rest, dry and after immersion in water, and safety after a twelve foot drop on concrete. Of these various trials, D.Arm.D. was to be responsible for release and jostling trials of bombs, and fuze safety trials from 12 feet and from a taxying aircraft. The remainder were to be arranged by D.M.W.D., Admiralty. Later, aircraft safety trials were arranged at M.A.E.E., Helensburgh, where bombs were to be detonated electrically at depths from 6 inches to 4 feet so that the height of water pressure and the scatter of fragments might be measured.

By April 1943, the greater part of the proposed trials had been completed, although development was destined to continue for a much longer period. Three trials only had not been satisfactorily completed: jostling trials for the bomb, and safety trials from small heights and from a taxying aircraft for the fuze. D.Arm.D. anticipated that these would be successful and in June signalled Coastal Command that the bomb and fuze (No. 866) were cleared for operational trials in Liberator aircraft. At the same time he placed a development order for a further two thousand bombs in addition to the original development order for two thousand placed by D.M.W.D. At the same time the order for two thousand fuzes was increased to four thousand.

Little so far has been said about the fuze, which, like the bomb, was developed by the M.D.1 under the direction of the Admiralty. The requirements of this fuze were that it should arm in the air, and should operate on impact with the U-boat either on the surface or submerged ; it must not operate on impact with water. The developed fuze was originally known as the 'Trident' but later received the official number 866.

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[1] A.M. File C.S. 15474.

[2] M.A.P. File S.B. 36570/1.

By June 1943, the outstanding trials referred to above had been completed at R.A.E. Jostling trials were unfortunately inconclusive: the fuze trials were however successful and showed that the bomb with its air-armed Trident fuze, and with American fuzing gear was safe when accidentally released from a taxying aircraft.

In preparation for operational trials by Coastal Command, initial trials to test the release system in the Liberator were completed at Beaulieu in that month. The small size and unorthodox shape of the bomb, and the necessity for very small spacing of sticks, to ensure that at least one bomb would be lethal, called for specially designed stowage and release systems. Two types of carrier were designed by M.D.1, one for the Liberator and one for the Halifax: seventy-two bombs could be carried in each aircraft. British type (Mark VI) distributors were used.

The Beaulieu trials—from 400 feet at 200 m.p.h. against a ground target representing a conning tower showed that while sticks of bombs were not uniform in spacing, the greatest interval with the distributor set at 0·35 seconds (to give 20 feet) was 23 feet, which was still considered to give a good chance of a kill. This method of bombing was necessary to obtain a direct hit—a near miss being ineffective—and was dictated by the width of the target. At the same time however, this spacing brought the bombs within the range of sympathetic detonation.[1] The minimum safe height for attack was an important factor and this was assessed by C.S.A.R. at 350 feet, this figure being accepted by D.Arm.D. until further data were available, and the bomb was now ready for operational trials.[2]

By mid-September, the operational experience of Coastal Command had been very limited. Trials of the bomb had commenced in No. 224 (Liberator) Squadron in which six aircraft had been specially modified to carry seventy-two bombs. Mark III low level bomb-sights had been used and attacks had been as far as possible, in accordance with the tactical instructions issued, i.e., on the beam and from a height of not less than 350 feet.

Only three attacks had been made, none very satisfactory. In the first on 2 July, twenty-four bombs were released in error with a stick of depth charges: the U-boat was damaged but whether by bombs or depth charges it was impossible to say. On the following day twenty-four bombs were released on a first run followed by depth charges on a second. The U-boat was assessed as 'known sunk,' but again it was not known to which weapon the credit should go.[3] In a third attack with bombs a hit was obtained but evidence showed the probability that no damage to the U-boat resulted.

The conclusions formed by the Command as a result of these very indecisive attacks were:—

(*a*) That the bomb could be aimed with reasonable accuracy.

(*b*) That bombs may detonate without striking the U-boat. (The requirement was that they should not do so.)

(*c*) In the heat of attack pilots came down below the safety minimum of 350 feet and aircraft were damaged by splinters.

[1] M.A.P. File S.B. 36570/4.

[2] Very reluctantly: the problem of damage to aircraft by its own bombs, due to sympathetic detonations, caused a very serious hazard to the aircraft engaged, and had not received complete attention. The whole question seems to have been left in the hands of the Research Department (C.S.A.R.), M.A.P. File S.B. 45460, dated 28 June 1943.

[3] A.M. File C.S. 15474.

(*d*) Some damage to the U-boat was inflicted.

(*e*) But that the bomb had not the power of inflicting the immediate and devastating damage which can sometimes be produced by a depth charge.

Apart from its meagre operational value, the preparation and loading of the bomb was criticised as needing very special care and occupying two and a half times as long as for depth charges: the carrying devices were delicate and easily made unserviceable. Finally the Command considered that a load of bombs with its exposed fuzes was more vulnerable to gunfire attack than a load of depth charges.

On 17 September 1943, the Aircraft Anti-U-Boat Weapons Sub-Committee met to discuss this operational report and a paper by D.S.R. (Admiralty) on the relative value of the 35 lb. A.S. bomb and the Mark XI depth charge. The findings of the Committee after consideration of these papers were very guarded, but in the main they were not very favourable to the bomb. The main finding is quoted :—

> 'Only in the case of attack of surfaced U-boats and where the track direction of attack may be avoided without prejudicing the chances of a kill, can a case be argued for the use of the 35 lb. A.S. bomb in preference to the depth charge.'

Even this limited opinion was qualified by reference to the greater moral effect of an unsuccessful depth charge and its secondary damage potential.

It will be noticed that so far the 35 lb. bomb had only been considered as a low height weapon. There was however about the middle of 1943, some change in the tactics adopted by U-boats: they had begun to operate in 'packs,' and there was a growing tendency for them to fight back rather than seek immediate escape by diving. This meant that the attacking aircraft might have to seek safety in height, and with the depth charge being suitable only for low height attack it was thought that the 35 lb. bomb might be used from medium heights (5,000 to 6,000 feet) if its ballistic properties could be improved.

Accordingly, a series of trials was held at the Orfordness Research Station in August 1943, using bombs with specially faired noses to increase the terminal velocity and improve the ballistics. The T.V. was almost doubled, but ballistic consistency remained poor. Special stowage and release trials were also done by A. & A.E.E. in August and October, using stowage and release gear designed by R.A.E. including a thermionic valve distributor—in an effort to get the accurate and small spacing necessary. Comments by A. & A.E.E. such as 'The scatter on the ground more closely resembles a salvo than a closely spaced stick, being irregular in line, range, and in the relationship between order of release and order of impact,' and 'The equipment releases bombs as required to achieve an accurate stick, but the ballistic behaviour of the bombs and the aerodynamic characteristics of the aircraft cause the final pattern to bear little relationship to that intended,' were among the conclusions leading to the recommendation by that establishment that the 35 lb. bomb as then carried and released should not be accepted for Service use.[1]

By the end of 1943, the grave doubt that the bomb, even if dropped accurately, was a useful weapon, and the complications involved in carrying and releasing it, made it highly necessary to decide its future. On 1 December, a War Cabinet

[1] M.A.P. File S.B. 36570/6.

Meeting on Anti-U-boat Warfare had placed before it the latest position. The results obtained by Coastal Command had been discouraging, and the Command had, after the three unsatisfactory attacks referred to earlier, abandoned entirely the use of the bomb. The Naval Staff stated that they had no requirement for it for Naval aircraft. Attempts to use it successfully from various altitudes had failed. In fact it seemed that the immense labour that had gone into its production had been wasted.

The meeting agreed that attempts to improve ballistics would not be justified, for they meant a complete new design. The random spacing due to poor fall was bound to reduce the lethal value, though the amount was unknown; photographs of water splashes from a Coastal Command Liberator were suggested, but the specially equipped Liberator no longer existed having long ago reverted to its orthodox load of depth charges.

Further trials were, however, arranged between Coastal Command and R.A.E. on their range at Pawlett Hams, and served only to verify the earlier findings of Orfordness and A.&A.E.E. In theory the spacing should have been 15 feet, and the length of a stick of 24 bombs, 345 feet. The actual length of sticks on trial from 5,000 feet was between 800 and 1,050 feet, apart from line scatter up to 100 feet. As before, the points of impact bore no relation to the order of release.[1]

At the beginning of 1944, the supply position was that of the 6,000 ordered by D.Arm.D. for development, approximately 3,000 had been delivered—none since December 1943, and of this quantity 1,500 still existed; nearly 6,000 fuzes had been completed. So that even if the bomb had been of some value, Coastal Command with its one aircraft was adequately supplied with bombs for a long period. Even then no decision was made to cease production at once. In April 1944, however, the firm manufacturing the bombs was compelled to review its commitments owing to cuts in gas and electric power, and decided that 'Project 64'—the 35 lb. anti-submarine bomb—was probably one of 'no great urgency'. D.Arm.D. agreed to stop all further production and to cancel the last order for 2,000 bombs.

In all, three thousand two hundred and eighty-nine 35 lb. A.S. bombs had been completed and filled. Apart from those bombs expended in development trials, there are records of ninety-six bombs released against three U-boats, with no evidence to show that any of these was successful.

In April 1944, the Operational Research Section of Coastal Command made a careful analysis of the use of the bomb by comparison with the 600 lb. A.S. bomb. At best this showed that either weapon might be expected to kill the same number of U-boats; but the 35 lb. bomb lost heavily in difficulties of fitting and maintenance, destruction of tactical freedom, and in the almost entire absence of secondary damage resulting from a near miss. It is not therefore surprising that there was little enthusiasm for its use in Coastal Command, and none in the Fleet Air Arm.[2]

The 250 lb. A.S. bomb: Marks V and VI

Although the 250 lb. depth charge with its shallow-firing hydrostatic pistol was by far the most efficient anti-submarine weapon developed before 1943, and although it was destined to remain the standard anti-U-boat weapon for both

[1] M.A.P. File S.B. 36570/7.
[2] A.M. File C.S. 15474.

the Fleet Air Arm and the R.A.F. until the end of the war, its disadvantages were obvious. In the main these were twofold: the strength of the case and the necessity for shallow firing imposed operational limits of height and airspeed, which, in August 1943, were 750 feet and 173 knots; and the low terminal velocity of the charge (600 feet per second) made it impossible to aim accurately with the Mark XIV bombsight (the latest type) at heights above 1,000 feet.

Although these limitations were partially removed with the development of a modified depth charge—the Mark XIV[1]—it was evident that the depth charge could not without complete re-design be made a universal anti-submarine weapon capable of being used from all operational heights from 50 to 5,000 feet, and at all modern bomber aircraft speeds.

The whole question was discussed at a meeting of the Weapon Sub-Committee of D.A.S.W.'s Anti-U-boat Committee, who recommended that a meeting should be arranged between D.Arm.D., the Design Department of the Royal Arsenal, and D.S.R., Admiralty, to review anti-submarine bomb design and if possible to submit recommendations on the lines which future design should follow.

This meeting was held on 6 April 1943, D.S.R., Admiralty having prepared an assessment of the merits of the various existing A.S. weapons. From this it appeared that the 250 lb. depth charge was 'not far from being the best bomb for general use from low heights, in Coastal Command,' but that it had certain disadvantages which could be overcome in a new design of bomb.[2]

The meeting then proceeded to lay down certain requirements which the new bomb must meet. A high T.V. for accurate bombing from heights up to 5,000 feet: a hydrostatic tail fuze to fire at 25 feet depth: ability when dropped from a low height to withstand a dry hit without detonating, and to remain in a fit state for detonation should it sink to the required depth: ability from greater heights—where the safety of the aircraft ceased to be jeopardised—to detonate instantaneously on a dry hit or at 25 feet on water impact: these were the main conditions to which the meeting agreed.

D.S.R. (Admiralty) assessed the probable efficiency of the new bomb, compared with the 250 lb. depth charge, from low heights, at 10 per cent. better, and compared with the 600 lb. A.S. bomb from medium heights, at 25 per cent. to 40 per cent. better. This A.S. bomb would further have the very great advantage of being a single weapon suitable for use from any height.

D.S.R.'s assessment was a strong argument—if any were needed—for the development of a bomb. It was followed by a paper prepared by the C.-in-C., Coastal Command, advocating the development of an anti-submarine bomb without delay.[3] As a result of the combined opinion of D.S.R. in the Admiralty and the C.-in-C., Coastal Command, in the R.A.F., A.C.A.S.(T.R.) asked D.O.R. to prepare a schedule of Operational Requirements, so that M.A.P. could get ahead with development work without delay. A brief list of these requirements follows :—

(*a*) The bomb must be suitable for carriage in all 250 lb. stowage positions.

(*b*) The fuzing arrangements must be such that—

(i) If the bomb is dropped 'live' from any height from 50 to 5,000 feet into water it must fire hydrostatically at a depth of 20 to 25 feet.

[1] *See* Chapter 4.
[2] M.A.P. File S.B. 46554.
[3] Anti-U Boat Committee paper No. 199.

(ii) If the bomb is dropped 'live' from any height between the minimum safe bombing height for the weapon and 5,000 feet, and a hit is obtained on a U-boat or other hard target, it must detonate after a short delay of such duration that it will do the most effective damage.

(iii) If the bomb is dropped 'live' from any height between 50 feet and the minimum safe bombing height for the weapon, and a hit is obtained on a U-boat or other hard target, it must not detonate on impact but must remain in a condition to give detonation subsequently when initiated by its hydrostatic pistol at between 20 and 25 feet depth.

(iv) If the bomb is dropped 'safe' it must not detonate as a result of impact with any type of target.

(v) The fuze must be such that the weapon will not countermine when released in sticks having a spacing between bombs of 40 feet, and it is desirable that countermining should not take place even with a spacing of 30 feet.

(*c*) The bomb must 'function' reliably after release from any height between 50 and 5,000 feet at speeds between 85 and 310 knots.

(*d*) The trajectory of the bomb must be consistent both in air and water. The minimum acceptable terminal velocity for the bomb is 1,000 feet per second.

(*e*) The bomb should be suitable for filling with Torpex. The weight of the main filling should not be less than 150 lb.

(*f*) The bomb must be suitable for carriage in British and American aircraft in the maximum quantity which space and weight will permit, and in a manner which will permit bombs to be released in 'sticks.'

(*g*) The bomb and its design must conform with the standard Royal Air Force requirements for safety in storage, handling, loading and carriage in Service aircraft.

(*h*) The design of the bomb and its fuzing arrangement is to be suitable for quantity production.

These were strenuous conditions and foreshadowed a long period of development. As a concession to the early production of a preliminary mark the height limit of 5,000 feet was reduced to 2,000 feet if by this means the weapon could be produced more quickly.

On 15 August 1943, A.C.A.S.(T.R.) asked C.R.D. to authorise the design, development and production of the new bomb on high priority. Copies of the requirements were sent to the Admiralty, to D.Arm.D., and by him to the Ordnance Board with an urgent request for a suggested design to meet them, by C.E.A.D.[1] D.Arm.D. suggested that a new impact fuze might be designed to meet the fuzing requirements, but that the R.A.E. designed hydrostatic fuze (No. 895—already referred to in this chapter) should be used for preliminary trials. As there had already been a 250 lb. anti-submarine bomb dating from pre-war years, and of entirely different design, the new bomb in its first form was given the name '250 lb. A.S. Type A'. C.E.A.D.

[1] A.M. File S. 4925.

used, as a guide to preliminary design, the general shape and construction of the 600 lb. A.S. bomb—a cylindrical body with break-away nose fairing and tail.

The choice of case thickness presented some difficulty for there were conflicting requirements: it must be thin enough to give the maximum charge/weight ratio, and heavy enough to withstand a dry hit on a U-boat without breaking up. One-quarter inch was chosen though it was considered barely sufficient to meet the latter requirement.

The best method of manufacture and the most suitable material were also in doubt, and it was decided that quantities of bombs made by various processes and with various types of steel must be made for comparison. In the first place orders were placed for fifty bodies made by pressing two halves of 35/40 ton steel and welding, and fifty seamless tubular bodies with pressed noses: also for fifty bodies from seamless tubular steel 24/30 tons tensile strength with the nose swaged in. Later, two further modifications to manufacture were added—35/40 ton butt-welded tubing and 20/30 ton seamless tubing and fifty bombs made by each process were ordered.[1]

It may be noted at this point that two other designs—known as Type 'B' and Type 'C'—were considered by C.E.A.D. Type 'B' was a penetrating bomb intended to penetrate the pressure hull without breaking up. A pointed nose was to be provided, covered by a blunt nose fairing which would only be detached on a 'dry' hit, and would thus ensure a good under-water path. Type 'C' was to contain a hollow-charge in the nose. Neither of these types was developed.

From December 1943 onwards commenced a series of trials with scale model and full size bombs. In December and January, a series of trials with quarter scale models by M.A.E.E. at Helensburgh, to investigate the under-water trajectory at various angles of entry, showed that except at very shallow angles of entry the bomb travelled stably in an open cavity to a depth considerably greater than the required firing depth of 25 feet.[2] From this it appeared that hydrostatic firing at the required depth would not be possible with the present bomb shape and that the under-water drag would have to be increased. In January, another series of trials with scale models supplied by C.E.A.D. was completed at the Road Research Laboratory, to investigate the possibilities of ricochet. Models were fired from a mortar to strike a sheet of water. These trials showed that at angles of entry of below 9 degrees ricochet occurred, and that this was probably independent of velocity at entry, at any rate within the range of velocities to be expected.[3] During this period C.E.A.D. was preparing designs for a baseplate so that the full scale bombs could be fired from a gun against representative plate targets, and D.N.C. was preparing suitable targets.[4]

The Weapons sub-committee of the Aircraft Anti-U-Boat Committee met on 30 December and agreed that the shape of the nose, and possibly the diameter, would have to be altered to give under-water instability, if shallow firing with a hydrostatic pistol was to be achieved. Model tests with the new design were arranged. Re-design of the pistol so that the presence of a cavity would not affect its firing by leading water from the nose to a pocket containing the pistol was discussed, and trials of this modification arranged.

[1] M.A.P. File S.B. 46554.
[2] M.A.E.E. Report No. H. Arm. Res. 19.
[3] M.A.P./104/A.C.W.—K.L.C.F.
[4] O.B. Proc. No. 26413. 4 February 1944.

There was some disagreement at the meeting on the subject of the Air Staff requirements : some members frankly stated that they were incompatible, and impossible to meet, particularly those dealing with strength and charge/weight ratio, but the majority agreed that a design to meet the requirements might be devised. As a result, three alternative designs were prepared to diminish the depth of cavity, and sent to M.A.E.E. for tank trial in March 1944.[1]

Firing trials against 1 inch M.S. plate at an angle of 50 degrees to the normal of the line of fire were concluded at Shoeburyness in May 1944.[2] Bombs constructed in the various methods described earlier were tested and the trials showed that the seamless tubular body with swaged nose was the most suitable. This indeed was the only type which showed no sign of longitudinal cracks after impact. Moreover it was comparatively easy to manufacture in quantity.

By July 1944, a Report from the M.A.E.E. on the behaviour of the re-designed model bombs was received, showing that there was no marked improvement.[3] It was shown however that improvement could be effected by designing the bomb on the lines of the 600 lb A.S. bomb, with ' skew ' nose. The effect of this skew, or sloping nose, was to cause the bomb to come into a broadside position in the water at about 6 feet depth, so that, at the proposed firing depth of 20 feet, the cavity had completely closed. This model became known, rather confusingly, as Type ' C '. The results of these model trials were confirmed by full scale trials in September 1944, when it was shown that the skew nose had even more effect on the full scale bomb than on the model.[4]

In September, a series of depth of firing trials with full scale bombs Type ' C ', fitted with No. 895 hydrostatic fuzes, was completed at the Fairlie Range by M.A.E.E.[5] The new bomb followed the design of the 600 lb. A.S. bomb, and was fitted with a nose fairing and a tail, both of which were shed on impact. The nose was concave, and set at an angle, away from the suspension lug. Accommodation for a nose impact fuze was provided. The tail (hydrostatic) fuze was No. 895 set to fire at a depth of 18 to 22 feet. The tail resembled that of the 600 lb. bomb, but had two square holes in the cone to take the fuzing wire. The diameter was 13 inches, the length 42 inches.

Sand filled bombs with live tail and dummy nose fuzes were dropped, fifteen from 50 feet and fifteen from 500 feet, at an airspeed of 180 knots. All fired except one which was a ricochet, at an average depth of 24 feet. Depth of firing tended to be greater at the lower height of drop. At angles of entry below 18 degrees bombs tended to ricochet. Entry and under-water ballistics were good.[6] These trials were very satisfactory and production was at once increased so that more comprehensive trials might be made. At the same time the bomb received its service name of ' Bomb H.E. aircraft 250 lb. A.S. Mark V Air '. It should be noted that there was, so far, no nose impact fuze available, although design had commenced.

In its manufacture, seamless steel tube was used for the bomb body and both ends of the bomb were pressed in one operation. This was the first time such

[1] M.A.P. File S.B. 46554.
[2] Shoebury Report No. 70/13/4. 7 June 1944.
[3] O.B. Proc. No. 28494. 2 August 1944.
[4] M.A.E.E. Report HB/TS 6005/S.R. Arm. 15/R.A.S.
[5] M.A.E.E. Report No. H. Arm. 126.
[6] O.B. Proc. Q.2819 (Appendix).

a method had been used in bomb construction. Welding was thus entirely eliminated from the body construction with a resulting increase in strength and a saving in labour.

The additional trials referred to above were concluded at Fairlie Range by the end of February 1945 and gave good results. The hydrostatic fuze was set to detonate at 23 feet, and the mean depth of detonation for thirty-five bombs was 25 feet. Forward under-water travel was consistent and sideways travel not excessive. No ricochets were recorded from heights of release varying between 550 and 47 feet.[1] Development of the bomb had now reached the stage where its introduction into service could be contemplated, and in March 1945 'Advanced Instructions' for its use were promulgated.

There was one requirement however which still remained unfulfilled—that for instantaneous detonation on a 'dry hit' for attacks from heights at which the aircraft was safe from blast or splinter damage. This was to be met by the fitting of a pistol in the nose of the bomb which could be selected by the pilot or not, according to his height. Such a pistol was under design by C.E.A.D. but trials were still incomplete.[2]

By the middle of 1945 the first five hundred bombs were issued to Coastal Command for operational trials.[3] No opportunity however occurred for such trials, and only an insignificant number were used in operations: the great majority of the initial Mark V bombs used were in fact expended in observed experimental trials, by M.A.E.E. Felixstowe, at Fairlie Range, in July and August 1945, when fifty-three bombs were dropped from heights between 600 and 30 feet. These trials showed that depth of detonation, set at 23 feet, averaged nearly 30 feet, with a maximum of 38 and a minimum of 23, and that the bomb had a seriously high failure rate—in the neighbourhood of 11 per cent.[4]

[1] M.A.E.E. Report HB/Arm./5001/4S and M.A.P. File S.B. 46554.
[2] The bomb so fitted became Mark VI.
[3] M.A.P. File S.B. 46554.
[4] M.A.E.E. Report FX/102/4 Arm. and M.A.P. File S.B. 46554.

CHAPTER 4

DEPTH CHARGES

The 450 lb. depth charge, Mark VII

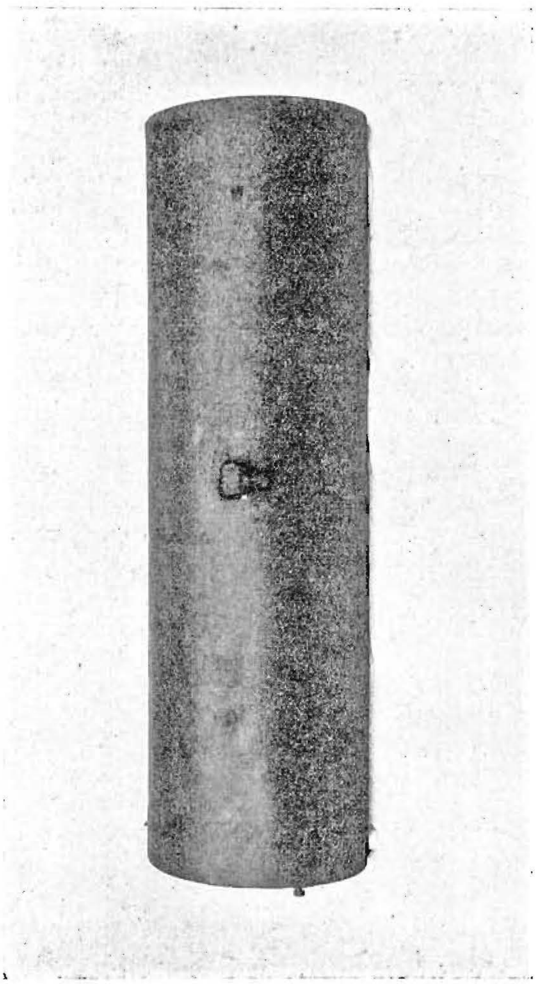
Up to the end of 1939, Coastal Command aircraft had sighted fifty-seven submarines, had attacked forty and had damaged eight. In January 1940, six U-boats were sighted, four attacked and one destroyed : in February the corresponding figures were fifteen, eleven and two damaged : in March there were seven sighted, six attacked without success.

The submarine is an extremely elusive and difficult target. It is likely to be sighted only in daylight and rarely can an aircraft expect to approach a submarine without being itself observed. There is thus little time for a calculated run-up to the target, which, even if it is still totally on the surface, is extremely small, but which has probably partially or completely disappeared and finally there is seldom any obvious evidence that damage or destruction has been effected.

It was natural that the anti-submarine bomb should be blamed for such poor results, although of course there were many other reasons. This opinion was occasionally confirmed when anti-submarine bombs were dropped enthusiastically near British submarines, when the damage turned out to be negligible. Whatever the truth, the Command began at once to look for a more satisfactory weapon. The only available alternative to the A.S. bomb was the depth charge which had been the standard Naval weapon for the attack of submarines for many years. It had two points greatly in its favour : it had a hydrostatic pistol of comparatively simple design, while the A.S. bomb had a complicated, unreliable and non-watertight fuze : and it had a high charge weight ratio, approaching 70 per cent. compared with under 50 per cent. of the A.S. bomb. It had in addition a great tactical advantage ; it could be released from an extremely low height without the danger to the aircraft resulting from the similar release of an anti-submarine bomb which detonated instantaneously on impact with the submarine, or after delay, on impact with water. In either case there was a danger to a low-flying aircraft, for a bomb entering the water at a flat angle was liable to ' porpoise ', and might then detonate in the air or very near the surface.

Advantages were not wholly on the side of the depth charge : a direct hit did not result in instantaneous detonation, though it was hoped that the charge would roll off and detonate underneath : and the depth charge was not primarily designed for release from aircraft. Trials were carried out at the Torpedo Development Unit at Gosport with specially adapted Naval 450 lb. depth charges to determine their behaviour when dropped from aircraft. These trials were completed in November 1939 and stringent limitations of height and airspeed had to be enforced to avoid the possibility of the depth charge breaking up on impact.

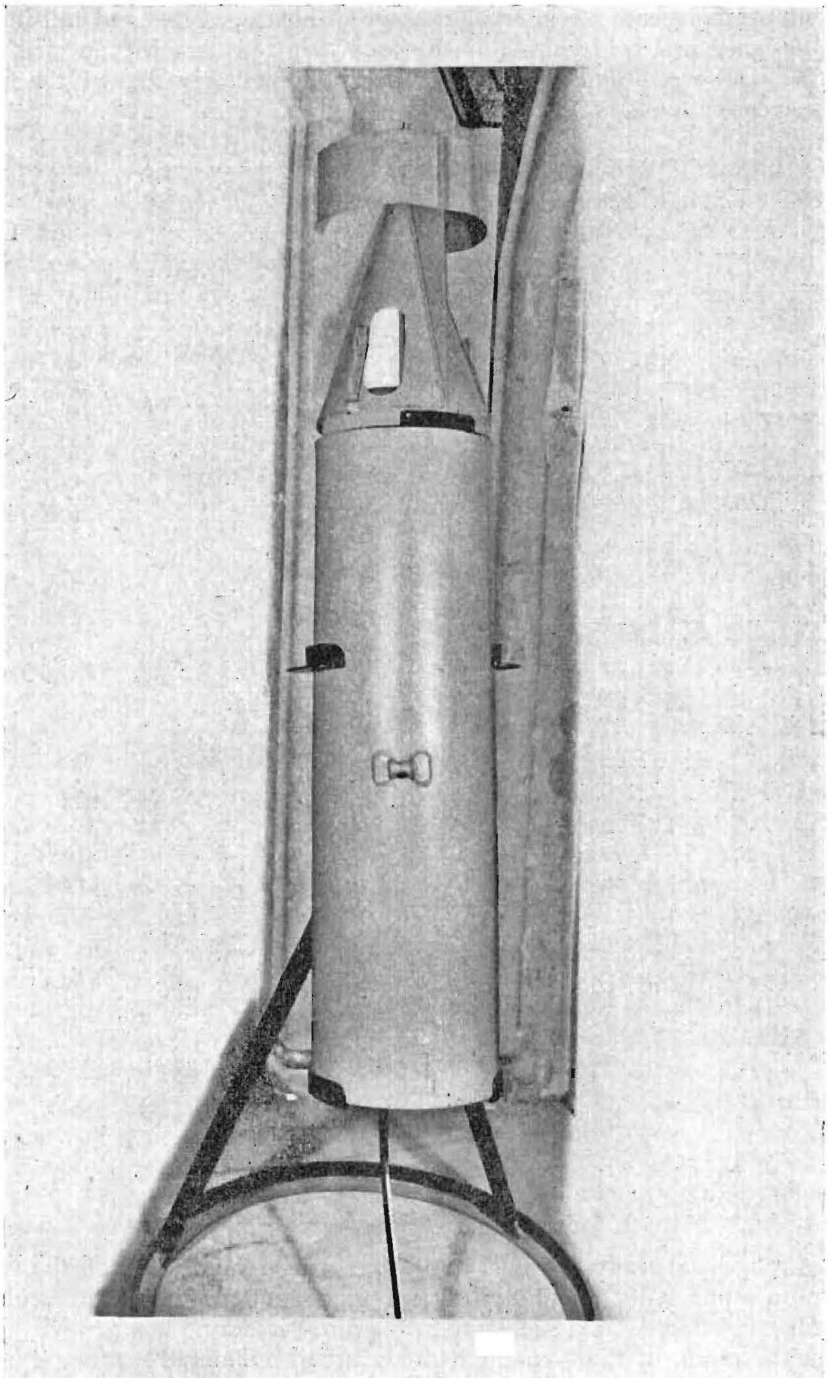
The balance, however, seemed to be in favour of the depth charge, and in March 1940, experiments to convert the standard Naval depth charge into the semblance of a bomb were commenced in the Torpedo Development Unit, Gosport, on orders from H.Q. Coastal Command. The conversion was necessary not so much to ensure stability in air, although this was important, but to reduce drag when charges were carried under the wings of a flying boat or an aircraft with no arrangements for internal stowage of bombs. Nose and tail fairings were designed and held in position by four steel rods which connected them together, and suspension from the bomb carrier made possible by the fitting of a suspension band.



250 LB. DEPTH CHARGE, MARK XI* C.C.

This rough and ready ' bomb ' was tested from a Sunderland off the Isle of Wight in April 1940, found to fall and to detonate satisfactorily and was immediately adopted as a successor to the anti-submarine bomb. It was not within the power of the Command to convert an unlimited number of depth charges, and in June 1940 the work was undertaken by M.A.P. to whom drawings of the conversion parts, nose, tail and suspension band were sent. Manufacture of one hundred sets of the necessary parts was put in hand by D.Arm.D.[1] At the same time urgent arrangement for the despatch of the parts to five Coastal Command Stations was made.

[1] M.A.P. File C.S.B. 7786.



250 lb. Depth Charge, Mark XI* C.C., fitted with Mark IV* Tail.

After these preliminary measures to secure with the least delay a supply of depth charges for operational trial, D.Arm.D. approached the Ordnance Board with a request that the Chief Superintendent of Design should consider the rough drawings prepared by Coastal Command, and prepare others more suitable for quantity production. By August, a further seven hundred depth charges had been obtained from the Admiralty—the estimated expenditure by Coastal Command for three months—and arrangements made for conversion sets.[1] The depth charge as an anti-submarine bomb was already established as the standard weapon, and, with many modifications, remained so until the end of the war, although 250 lb. anti-submarine bombs were often carried in addition.

The first major modification was an essential one to the pistol. In the original design of pistol (Mark VII) no safety arrangements such as are normally fitted to aircraft bombs for safe dropping were possible. Generally they were unnecessary as it would almost always be possible to jettison depth charges in deep water, away from shipping, in an emergency, and depth charges dropped on land would not be expected to detonate in any case. There was, however, one circumstance which involved grave risk. Should an aircraft crash into the sea while carrying depth charges, these would detonate on reaching the requisite depth and members of the crew who had escaped to the surface would almost certainly be killed. This could to some extent be avoided in the Sunderland, by setting the pistols inside the aircraft just before winding out the carriers. In other aircraft, particularly those in aircraft carriers, the danger was very real.

The Superintendent of Mine Design therefore undertook to produce a type of pistol which could be dropped safe. The depth setting on the pistol, instead of being set to the required depth by hand when charges were secured to the aircraft, was fitted with a spiral spring which constantly endeavoured to rotate a key away from its safe position. Rotation was prevented by a pin, connected with the fuzing box of the carrier, and a second pin was provided which could be inserted into a hole opposite each depth position and which would act as a stop to the spring rotated key. Thus the depth setting was made automatically as the charge left the aircraft. By leaving the fuzing control in the safe position, the retaining pin remained in position and the charge thus dropped ' safe '. The final design of pistol thus modified became Mark X.

The second important modification to the air depth charge was the improvement of the additional fittings at nose and tail and the suspension band.[2] All these parts had been hastily improvised in Coastal Command and were obviously capable of great improvement. Weaknesses soon became apparent but the chief trouble lay in the suspension band which was not designed for the violent acceleration and deceleration loads imposed by carrier landing and take-off. In October 1940 a meeting was held at R.A.E. to consider what improvements might be made, and it was decided that C.S.D. should be asked to re-design the fittings. The new design was completed by November.

Apart from minor modifications from time to time the 450 lb. depth charge remained in its original form throughout the war, and no further mention of it need be made. On the other hand numerous modifications to the pistol were found necessary to keep pace with changes in the policy of anti-submarine attack. These changes were mainly concerned with depth setting and as they

[1] M.A.P. File C.S.B. 7786/1.
[2] M.A.P. File C.S.B. 7786.

apply equally to the second type of depth charge used during the greater part of the war, it will be convenient first to give a brief history of this weapon, and then to describe the development of their common pistol.

The 250 lb. depth charge, Mark VIII

The 450 lb. depth charge was too heavy to be carried in reasonable numbers in such aircraft as the Fleet Air Arm Walrus and Swordfish and too bulky to fit into the internal stowage position in the Hudson, which, by the end of 1940, had become the standard General Reconnaissance aircraft of Coastal Command. It was therefore necessary to design a smaller depth charge which could easily be accommodated in these smaller aircraft, and as the most urgent need was for a weapon to replace the anti-submarine bomb in the Swordfish, the production of the new charge was undertaken by the Superintendent of Mine Design, Admiralty. The name given to this weapon was originally Depth Charge type 'F'. It weighed 246 lb. and contained 170 lb. of explosive, its charge/weight ratio thus being just under 70 per cent.

In November 1940 the 'F' type charge was available to all ships carrying aircraft, and to the Air Ministry. By this time its name had been changed to Depth Charge, Mark VIII.[1] It was a plain cylinder with a diameter of 11 inches and a length of 39 inches which was later increased to 56 inches by the fitting of a plain drum tail. No nose fairings were designed. The pistol was the standard Mark VII or the modified Mark X as used in the larger depth charge, for ordinary and catapult take-off, and live and safe dropping trials were arranged by D.Am.D. with A. & A.E.E. and R.A.E. Similar trials were organised by S.M.D. Admiralty to be undertaken by H.M.S. *Vernon*.

By December, R.A.E. had completed all the necessary strength tests for the severest catapulting loads likely to be encountered, and the results were considered satisfactory, and by the same date A. & A.E.E. had confirmed that stowage in Walrus, Swordfish, Albacore and Hudson was satisfactory, with certain minor modifications to carriers.[2] In the same month various dropping trials carried out by H.M.S. *Vernon* in conjunction with the Torpedo Development Unit at Gosport showed that the depth charge without tail was satisfactory from heights not greater than 200 feet at speeds not exceeding 220 knots: at greater heights and speeds, the charge was unstable and required the fitting of a light cylindrical tail which the Superintendent of Mine Design undertook to design. Meanwhile, on 23 January 1941, the new depth charge was cleared for use in R.A.F. aircraft, and Confidential Fleet order No. 142/41 was published by the Admiralty introducing both the Mark VII and Mark VIII charges. The pistol used was Mark X, that is to say the original Mark VII depth charge pistol with self depth-setting device which operated only after the depth charge had left the aircraft.

By May 1941, the Superintendent of Mine Design had completed his design for a cylindrical tail and dropping experiments had been made at Stokes Bay (Gosport) under the supervision of the Captain H.M.S. *Vernon*. Although the recovery gear fitted to the charges failed, and no examination for impact damage could be made, it was evident that the addition of an 18-inch cylindrical tail had corrected a tendency to ricochet at heights of drop of under 250 feet, and that flight in air had been improved, as had entry into the water.

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[1] M.A.P. File C.S.B. 11989.

[2] Walrus 4, Albacore 8, Swordfish 6, Hudson 8. M.A.P. File C.S.B. 11989.

The remainder of 1941 was occupied with various experiments with different designs of tail and tail fittings, carried out at Weston-super-Mare by D.M.D., at West Freugh by the Torpedo Development Unit of the R.A.F. and at M.A.E.E., Helensburgh. All of these experiments were hampered by lack of facilities for observing the under-water effect of the tail. As, towards the end of 1941, the policy of fitting tails was considerably modified, it is unnecessary to describe these experiments in detail.

This change of policy had its origin in a decision by the Anti-submarine Warfare Committee, and due largely to the researches of Professor Blackett, that successful attack on submarines could only be guaranteed if depth charges could be made to detonate at much shallower depths than heretofore. Depths of 15 to 20 feet were aimed at. This reduction in depth of detonation was primarily a matter of pistol modification, and from this point of view will be discussed later.

A secondary method of attaining shallow detonation was discussed at a meeting at the Admiralty on 21 January 1942, when the suggestion was made that by making the tail break away on impact, and by redesigning the shape of the nose of the depth charge case, shallow firing might be achieved in combination with a modified pistol.[1] The principle of redesign was the control of under water travel by means of a 'spoiler nose' the effect of which was to make the depth charge unstable, and to cause it to travel broadside on. Tank trials at the Admiralty Research Laboratory at Teddington with models gave promising results, and a Mark XI charge was accordingly designed, which had a concave nose, to give the desired instability on impact. By the middle of 1942, production of depth charges was concentrated on the Mark XI which in combination with a modified pistol had proved to be the most satisfactory anti-submarine weapon.

Reduction in firing depth of depth charges—Modifications to pistols

The original depth charge pistol had been that used by the Navy for Mark VII depth charges used from the decks of surface vessels, and which had a range of depths from 50 to 250 feet. The first modification to this pistol has already been described and was a method of increasing the safety of aircraft carrying depth charges, which might crash and sink, and whose charges on reaching the set depth, would detonate. The Mark X pistol was designed so that the pistol remained safe so long as the depth charge was attached to the aircraft, the depth being set by a spiral spring after release. The range of depth settings however, remained as before.

By the middle of 1941, it was realised that for the successful destruction of U-boats, a much shallower depth setting than that provided in the naval pistol was required, and a figure of 20 feet was set as the goal. An immense amount of labour and research on the part of the Superintendent of Mine Design and his staff, between the middle of 1941 and the latter part of 1942, was expended on what proved to be a most difficult problem. Reduction in the strength of the firing spring, the first obvious step to take, proved ineffective; and it was realised that the trouble lay in the rate of entry of water to create the necessary hydrostatic pressure to fire the pistol. An increase in the number of water entry ports resulted in partial success, and by April 1942, firing at from 30 to 35 feet had been achieved.

[1] M.A.P. File C.S.B. 11989.

It was at this time that modification to the design of the depth charge case as well as to the pistol were found necessary. Various other modifications to the internal construction of the pistol resulted finally in the No. 16, with a single depth setting of 22 feet. The Mark XI depth charge with No. 16 pistol remained the standard combination throughout the rest of the war.

The 250 lb. depth charge, Type 'M'

The 250 lb. depth charge had proved to be an efficient weapon so far as it went, but it had many inherent faults. The weak structure of its case enforced severe limitations of height of release and air speed: the pistol had not been designed to withstand severe impact with the water, moreover little was known of the under water behaviour of the weapon, except that it was probably highly erratic. The fact was that the depth charge had been adopted as an emergency measure and had had none of the trials which a new weapon should pass before acceptance. There were indeed at that time no facilities for such trials, and there is no doubt that the testing of weapons for the attack on submarines—from time to time throughout the war declared to be the most important of all targets—had been sadly neglected. Practically nothing was known of the under-water behaviour of the bombs, and little of under-water detonation—so little that the scale of distances from a submarine at which the detonation of a given charge would ensure destruction differed in the Navy and the R.A.F. by several feet.

The only trials which had been completed by the end of 1940, were various statistical trials at M.A.E.E., Helensburgh, and these consisted in dropping live charges and observing whether they detonated or not. From these observations, rough limits of height and airspeed were computed, inside which detonation was fairly certain. By the middle of 1941, it had become apparent that these limitations were too restrictive, and that the detonation of depth charges was in general too deep. The long series of modification to the pistol to improve the latter defect and obtain the shallowest possible firing depth has already been described, but it was not until 1943 that serious improvements in height of release and maximum air speed were made. At a meeting on the 11 August 1943 of the Anti-U-Boat Committee, it was decided that the maximum height of release must be raised to 1,500 feet and the speed at release to 250 knots. This change in height of release had become of paramount importance, for U-boats at that time, instead of diving immediately on sighting an aircraft, preferred often to stay on the surface and retaliate.

A new design of depth charge was evidently urgently needed and D.O.R. at once authorised D.Arm.D. to commence work on a fresh design. At the same time the Director of Torpedoes and Mining, Admiralty stated the requirement for a modified depth charge to the Superintendent of Mine Design at Havant.[1] The modifications were to be 'simple and which require no tools.' A height of release of 1,000 feet was to be essential and of 1,500 feet if this could be achieved without undue difficulty. The 1,000 feet-charge was to meet immediate requirements, but concurrently work was to continue on the 1,500-feet charge which was the ultimate figure aimed at.

By the middle of November, and with the assistance of R.A.E. two designs had been produced by the Superintendent of Marine Development and arrangements were made with the Director of Torpedoes and Mines for the manufacture

[1] D.T.M. Admiralty, 20 August 1943.

of fifty of each for comparative trial.[1] These were described as types M/A and M/B. In the former the requirements of air and water ballistics were incorporated in the Mark XI depth charge case with a strengthened and modified nose cap: in the latter good air ballistics were assured by a separate nose cap which was detached on impact with the water. Both types were fitted with a cone and drum tail.

In May 1944 firing trials with type M/A were concluded in the R.A.F. experimental area off Lady Isle (Clyde estuary) under the superintendence of the Captain, H.M.S. *Vernon*, and with assistance of M.A.E.E. Helensburgh. Twenty-two charges were dropped from 1,500 feet at speeds from 120 to 210 knots. The results showed firing depths between 40 and 70 feet (with D.C. pistol No. XVI), which were much greater than those expected or desired.[2] These trials were followed on 8 and 9 May by similar trials of the M/B type at similar speeds and heights with the same result—too great depth of firing.[3]

Meanwhile extensive ballistic trials by the Orfordness Research Section of R.A.E. had shown the new charges to be slightly unstable, due probably to the tail design.[4]

The hoped for rapid development of the improved depth charge, the Air Staff requirements for which were now a year old, was thus unfulfilled, and both types M/A and M/B were abandoned. Work commenced on a type M/C, but, in July 1944, D.Arm.D. suggested to D.Arm.R. that work on this modification might be abandoned. By that time an entirely new anti-submarine bomb of 250 lb. was well under development, and might be retarded if the development of the 250 lb. depth charge should continue.

The matter was discussed by the Anti-U-Boat Committee in August 1944, and it was agreed that further work on the depth charge should be undertaken, but on low priority.[5] S.M.D. had meanwhile produced an M/D design with a flat nose cut off at an angle of 5 degrees, and a break-off air ballistic nosecap of bakelite to correct the 'skew' nose during the air fall of the charge. This looked promising and it was agreed that it might be cleared 'without extensive trials.'

Trials, on similar lines to the previous experiments, were made at the beginning of August, in the Firth of Clyde.[6] The depths of detonation, with release from 1,500 feet at 200 knots showed a great improvement over Types M/A and M/B, varying from 16 to 24 feet. D.T.M. accordingly recommended the acceptance of the M/D type under the name of depth charge 250 lb. Mark XIV,[7] and acceptance trials, carried out in the Firth of Clyde by the Fleet Air Arm in January 1945, were satisfactory.[8] The conclusions were that the Mark XIV was reliable at a mean depth of 19 feet between release limits of 50 to 1,500 feet and 120 to 250 knots: that it could be jettisoned safely and did not ricochet.

A further modification of the Mark XIV depth charge resulted in a Mark XV version. This mark was specially designed for the attack of U-boats fitted with the *Schnorkel* which made their appearance at the end of 1944. A submarine so fitted could obtain sufficient fresh air from the surface, not only to

[1] S.M.D. F. 1782, 16 November 1943.
[2] Vernon Report P. 253/44, 30 May 1944.
[3] Vernon Report P. 286/44, 29 June 1944.
[4] R.A.E. Arm. S. 560/B, 19 July 1944.
[5] M.A.P. File S.B. 30946.
[6] Vernon Report No. P 342/44, 28 August 1944.
[7] D.T.M. Admiralty R/S. 2601A/44, 19 December 1944.
[8] Vernon Report M.1008, 23 February 1945.

remain submerged for very long periods but also to recharge its batteries, an operation which previously could only be carried out while surfaced. For the destruction of such submarines, a detonation depth of 50 to 60 feet was required, in addition to the 20 feet needed for surface or near surface attack. The Mark XV depth charge met this need by the fitting of two pistols, one designed to detonate at 20 and the other at 50 feet. Both pistols were air armed and could thus be selected by the pilot before release. The development of the Mark XV depth charge was interrupted by the end of the war, and before acceptance trials could be made.

The days of the depth charge as an anti-submarine weapon were, however, numbered, the Marks XIV and XV designs were not accepted for service by the Royal Air Force. In August 1945 A.C.A.S. (Ops.) confirmed that there was no longer a requirement in the Royal Air Force for any form of depth charge,[1] the decision having been made after a lengthy discussion of the position by the Aircraft Anti-U-Boat Committee in July 1945,[2] and the production and development of all marks of depth charge were terminated. The Fleet Air Arm on the other hand decided to retain the depth charge until the new A.S. bomb should become a proved and reliable weapon.

Probably no individual weapon played such a long and important part in warlike operations as the depth charge which was in fact the only important anti-submarine air weapon during the whole of the war. This is the more remarkable as its early development began in a private venture by Coastal Command, in the rough improvisation of the naval depth charge.

[1] D. Arm. R., 20 August 1949 and A.M. File S. 81945.
[2] A.A.O. B.C. 23rd Meeting, 5 July 1945.

CHAPTER 5

THE 'W' BOMB

Plan 'Royal Marine' (W.A. 16)

Towards the end of 1939, a Plan known as W.A.16, with the code name 'Royal Marine', was devised by the War Cabinet with the object of 'reducing Germany's coastal and inland waterway traffic to the maximum possible extent by laying mines from aircraft.'

The Naval blockade had greatly reduced Germany's overseas trade since the outbreak of war, but could not interfere with her coastal and inland water traffic. At that time the only method of approach to German rivers and canals was by air and suitable aircraft weapons had to be devised. One of these was the 'W' bomb, designed to float down rivers to destroy on contact barges and bridges; or to be moored in canals. (For the attack of coastal and estuary shipping a second weapon, the magnetic mine, was developed.)

The requirements for such a bomb were that it should float freely some 3 feet below the surface: that if necessary it should moor itself in this position: that it should be capable of remaining at the bottom of a canal for a length of time up to several days, after which it should rise into position below the surface: that it should be safe when dropped from a low height and capable of withstanding impact on water: it was to be self-sinking after a prearranged period in case it should float into neutral waters. The weight of explosive was at first undetermined. In November 1939[1] trials by H.M.S. *Vernon*, and H.E. charges against dummy lighters, showed that the charge to be effective should not be less than 8 lb. In December, further experiments against a loaded barge showed that a weight of 8 lb. was insufficient, and that the minimum charge should be 20 lb.

The origin of the 'W' bomb is somewhat obscure. Its design appears first of all to have been considered by Major Jeffris of the War Office but investigation leads to the conclusion that some of the credit for the design must go to Mr. Midgley of Messrs. Midgley Harmer, builders of pipeless organs. The problem seems to have been discussed between Major Jeffris and a Mr. A. M. Low. Low turned to Midgley in October 1939. In a few days Midgley had produced a small bomb weighing 3 lb., of simple design and equipped with a radial 'spider' of wires, rather like the ribs of an umbrella, which, ordinarily compressed, when released, sprang out and acted as sensitive contacts through which an electric circuit could be closed to detonate the bomb—a principle which persisted throughout the development of the weapon.

On 28 November 1939, a Conference was called at the Offices of the Ordnance Board to discuss the design of the bomb, then a matter of great urgency, with Group Captain Huskinson, R.A.F. representative on the Board, in the chair.[2] The design suggested by Midgley, which had by this time been made up at Woolwich, Major Jeffris having supplied the drawings, was discussed and various modifications suggested. Arrangements were made for R.A.E. to investigate the carrier problem and static and dropping trials were arranged.

[1] M.A.P. File S.B. 2315/1.
[2] O.B. 'W' 1 File.

On 2 December 1939, a further meeting was held at the Ordnance Board Offices. Various points of design were discussed, and an order for one hundred bombs placed with the Chief Superintendent of Design, Woolwich. Dropping trials in the Staines Reservoir were agreed on, after the consent of the Metropolitan Water Board had been obtained.

Yet another meeting was held on 6 December, by which time a report from H.M.S. *Vernon* had been received, recommending 20 lb. as the least weight of charge to be effective. This meant a re-design, the dimensions of which were increased to 10 inches diameter and 16 inches length ; the total weight was estimated as 30–35 lb. Experiments on soluble plugs were put in hand both by the Admiralty and by C.S.R.D. Woolwich, all work on the original small bomb was stopped, and the development of the larger bomb commenced. By 11 December, various other refinements in the design had been considered, such as an arrangement of cork floats to keep the bomb out of sight just below the surface, and a sinking device which would, after an interval, allow the bomb to rise.

On 21 December, six of the Woolwich bombs were dropped into Staines reservoir but were all unsuccessful. Their ballistics were bad and the bombs cartwheeled badly and received extensive damage on impact. Further trials on 27 and 29 December were again unsuccessful ; on the last date drogues were fitted to lessen the force of impact, but all bombs sank and did not reappear.[1]

On 29 December 1939, at a meeting held at the Air Ministry, with Air Vice-Marshal Tedder in the Chair, attended by representatives from the Ordnance Board, Directorate of Armament Development and the Directorate of Armament Production, Messrs. Midgley Harmer were given the contract for ten thousand bombs and containers.[2] Full working drawings of the 31 lb. bomb were completed by 13 January, and production had commenced by 3 March. The task of following and supervising the development of the bomb was given to Group Captain Huskinson, then a member of the Ordnance Board. Before a detailed account of the subsequent development of the bomb is given, it may be well to give a brief description of the various types which eventually came into existence.

The Mark I bomb was made up of a cylindrical casing of 10 inches diameter and 15 inches long, filled with a charge of 20 lb. T.N.T., the total weight being 35 lb. The bomb had a negative buoyancy, and to it were attached by lines, a number of cork floats. These corks were contained in a small chamber at the top of the bomb, which also contained the firing device—a number of wires arranged like the ribs of an umbrella. These were held together by a lid which also retained the corks but were arranged so that, on the removal of the lid they opened out radially, forming a number of projecting 'whiskers'. Two delay devices in the form of soluble plugs were fitted : the first, after two or three minutes in the water, freed the lid, releasing the contact wires and corks which then held the bomb suspended at a depth of some 3 feet and free to float with the current of the stream. The second was intended to sink the bomb after a lapse of six, eighteen or forty-eight hours (according to the type of plug fitted), so that it became inoperative in neutral waters. This type was intended for use in rivers.

[1] O.B. 'W' File.
[2] M.A.P. File S.B. 2286 AD/Arm P. 2.

For the still waters of canals, a Mark II pattern was designed in which the corks were attached directly to the bomb. At the bottom was a 5 lb. sinker and 6 feet of mooring cable. After entry the sinker was freed by a soluble plug, and moored the bomb 6 feet from the bottom. As the average depth of a canal is 9 feet, it was thus held some 3 feet from the surface. A third type (Mark III) was intended to destroy pontoon bridges, whose draught is about 1 foot. The Mark III bomb, by means of directly attached corks, floated just below the surface, and was intended to drift into contact with the bridge.

In all Marks, any contact with the radial wires completed an electric circuit supplied by a small battery, firing an electric detonator and the main charge. All bombs were fitted with a small drogue, designed by the Royal Engineers and Signals Board, to check their impact.

While production was going ahead with conspicuous rapidity, the tactical use of the bomb was discussed among other matters at the Admiralty on 15 January 1940, with the First Sea Lord in the Chair.[1] Air Vice-Marshal Tedder, Group Captain Huskinson and Major Jeffris were present.

The plan Royal Marine was discussed under four heads :—

(*a*) Drifting mines to be placed in rivers from the banks.

(*b*) Drifting mines to be laid in rivers by aircraft.

(*c*) Mines for still waters to be laid by aircraft.

(*d*) Mines for estuaries.

(*a*) and (*d*) were the responsibility of the Admiralty, (*b*) and (*c*) of the Air Ministry. For (*a*), mines were to be sent to France where the French Navy would be responsible for placing them in rivers.

Air Vice-Marshal Tedder gave proposed production figures for the Mark I (drifting) bomb, of which ten thousand had been ordered. Five thousand should be ready by the middle of February, and before the March moon. He stated that authority had been given for a second ten thousand Mark II (Moored) bombs. The First Sea Lord directed that all steps were to proceed on the highest priority.

On 24 January 1940, a Conference at the Ordnance Board, with Group Captain Huskinson in the Chair, discussed the requirements for the Mark II design referred to at the Admiralty Conference. It was to resemble the Mark I pattern as far as possible : it was to be capable of remaining at the bottom of a canal for periods up to one week, after which it would free itself and rise to a position just below the surface. Investigation into the design of soluble pellets to give these delays was undertaken by C.S.R.D. Woolwich.

The first dropping trials of the Mark I bomb were completed on 14 February. Eight bombs were dropped in Staines Reservoir four from 500 feet, two from 1,000 feet and two from 300 feet, of which seven successfully detonated, and arrangements were then made for further trials of production bombs. R.A.E. were to organise trials in the Reservoir to test the carriers (special W container and small bomb container), and the operation of the detonator. Live bombs were to be dropped on hard and soft ground at Porton to test for detonation, should the river or canal be missed. Bombs inert, but with live detonators,

[1] Military Branch Admiralty, 16 January 1940.

were to be drifted down the Thames. Rough usage trials were required and were arranged by C.S.D., whilst arrangements were made for the supply of dummy bombs for training, and experimental purposes.

At the end of February, two Mark I bombs were sent to A. & A.E.E. for test against a concrete target, as the Air Ministry had decided that detonation on the banks of a river or canal was undesirable.[1] The trial was completed on the hard target at Porton on 5 March, the bombs being dropped from 350 feet at 200 m.p.h. ; neither detonated.[2]

Meanwhile various other trials had been made, those on the Thames at Reading giving only moderate results.[3] On 28 February, two bombs were placed in the river, flowing at about 3 knots. Both armed in 2 to 3 minutes and floated on the centre of the stream for some three quarters of a mile. One failed to detonate when struck by the bows of a tug ; the second detonated when struck by an oar. Further trials on 1 March were more promising. Five bombs out of six armed correctly : four detonated against a tug. One failure was due to the bomb sliding among trees on the bank : the second was due to a faulty electrical connection. On 2 March, a test of production bombs was made from a Blenheim. Eighteen bombs were released from heights from 1,000 to 300 feet and all were satisfactory. One bomb from 1,000 feet hit the bank and was detonated successfully afterwards.

On 1 April, a trial of the Mark I bomb against a pontoon bridge at Wallingford, showed that this design was unsuitable for the destruction of such a target ; two bombs floated under the bridge, armed, but failed to detonate. It was evident from examination that for the destruction of a pontoon the bomb must float on the surface and the detonating contact wires must be just clear of the surface. This gave rise to a new requirement, culminating in the Mark III bomb.

During this time work on the Mark II pattern, the moored bomb for rivers, had gone successfully forward. A self-detonating sinker had been designed and, on 27 March 1940, a trial was completed in a reservoir near Kempton Park with samples from the production order of 1,500. Six bombs were dropped from 500 feet into 11 feet of water. Four bombs had 5 cwt. cable sinker lines, and two 500 lb. mooring cable : the lines in each case measured 5 feet.

After release the reservoir was partially drained, and three bombs securely moored were found at 7 feet 6 inches. On complete drainage the remaining bombs were found on the bottom : the sinkers had been released but, as water had entered the central tubes, the bombs were no longer buoyant. It was unfortunate that old bombs, which had already been dropped, were used for the experiment, and failure of a rubber diaphragm had caused the leakage. The 5 cwt. cable was badly kinked but the mooring line was completely satisfactory.

By 4 April 1940, bombs, redesigned for the attack of pontoons, were ready for trial. Two designs were tested : one in which all corks had been removed and some of the filling, additional upright wire contacts having been fitted, the second had corks reduced in size and attached to the top of the bomb : the contacts had been turned upwards and no reduction of filling had been made.

[1] Z.A.X. 143 26/2.
[2] A. & A.E.E. S. 503 Arm, 6 March 1940.
[3] M.A.P. File S.B. 2315/1.

Both types detonated successfully on contact with the pontoon, but the second was evidently more satisfactory as no loss of filling was involved. The bomb, thus modified, was given the name Mark III.

On 6 April the Air Staff agreed to the production of ' W ' bombs at the rate of 250 to 300 daily. A total of 23,000 was required of which 14,000 were Mark I, 6,000 Mark II and 3,000 Mark III. Deliveries of the bomb commenced on 3 March 1940 and by 11 June a total of 21,910 bombs had been delivered for operations ; this figure does not include the many hundreds of bombs used for trial and experiment. By April, a supply of bombs had been sent to eighteen Bomber and eight Coastal Command Stations. Courses of training for armament officers and armourers had been arranged and all was in readiness for any operation that the Air Staff might desire. This call was unfortunately never made.

It will be remembered that operation ' Royal Marine ' was planned in November 1939, and was conceived principally against shipping in the Rhine.[1] At that time it was hoped that equipment would be ready for such an operation by March 1940. By February, however, it became apparent that this could not be achieved and the Air Staff decided that, rather than undertake the operation on a much reduced scale, and with untrained squadrons, it must be postponed. A premature beginning would have sacrificed surprise and prejudiced the chance of success. Moreover, by February the Air Staff had concluded that an attack on the Dortmund-Ems Canal would be more profitable, but the canal was narrow, and many bombs might fall on the banks. (It was for that reason that the trials to show that the bombs would not detonate on land were made.) Should they detonate, the Air Staff considered that Britain would be open to a charge of indiscriminate bombing. (It must be remembered that this was less than six months after the outbreak of war, and no bombing of land targets had yet been undertaken under a restricted bombing policy.) It was therefore decided to postpone the operation which envisaged the dropping of Mark I bombs on the rivers Rhine, Elbe, Weser, Main and Neckar, and Mark II bombs in the Dortmund-Ems and Mittelland Canals, until the full moon of 22 April 1940, by which time 6,000 bombs would be ready.

Large numbers of bombs were despatched to France for the use of the Air Striking Force, but the evacuation of Dunkirk, and the general war situation, prevented any use of them against the enemy. The threat of invasion, and the commencement of an offensive bombing policy against invasion ports and German industrial areas, occupied all available aircraft, and by the autumn of 1941, Bomber Command informed the Air Ministry there was no operational requirement for the bomb, and returned all stocks held to Maintenance Units.[2] On 26 November 1941, V.C.A.S. ruled that the bomb should be put on the disposal list together with the early ' B ' bomb.[3] All bombs were reduced to produce.

The ' W ' bomb is an example of a weapon conceived in great haste and developed so rapidly that weak points in design were inevitable. Its outstanding disadvantage lay in the fact that it could not be stored. Small batteries and

[1] Plan W.A. 16 Plans Ops., 21 February 1940.
[2] M.A.P. File S.B. 2315.
[3] A.M. File S. 74585.

soluble plugs deteriorated rapidly, and were intended for immediate use. The bomb, too, was never completely safe. The dissolution of soluble plugs, which formed part of the safety device, and the possibility of electrical ' shorts ' made it a constant source of danger in storage or under preparation. On 22 June 1940, a serious accident occurred at R.A.F. Station Dishforth, in which two airmen were killed and a number severely burned, while engaged in ' defuzing ' ' W ' bombs. Damp weather affecting the soluble plugs or the electrical circuits, sabotage, and carelessness in handling the bomb were all suggested as possible causes.

CHAPTER 6

INCENDIARY BOMBS

Early history

Little progress was made during the First World War in the development of incendiary bombs. Until the middle of 1916, crude bombs filled with petrol, or petrol and T.N.T. were used and in 1917 a 10 lb. bomb filled with carcass composition was manufactured. Various bombs intended to burst in the air for the destruction of balloons were tried with little success as they were so much inferior to incendiary ammunition for this purpose. The first important step in incendiary bomb development was made in 1916, when Commander Francis Ranken designed the Baby Incendiary Bomb (B.I.B.), and organised a special filling factory for its production at Roslin Castle, near Edinburgh. It was produced in sufficiently large numbers by 1918 to cause considerable damage to the limited targets bombed in enemy countries in that year by the Independent Air Force.

This famous bomb which finally disappeared in 1939, after a life of twenty-three years, was designed to meet the requirement of non-penetration. It consisted of a small cartridge case of solid drawn aluminium filled with Thermite, the whole weighing but 5 ounces.[1] The cartridge was fitted into a tinplate container weighted at the nose and feathered at the tail to give it some semblance of a good trajectory. On impact the cartridge was ejected from the rear of the case and burnt fiercely and completely for several minutes. The bombs were carried in clusters in a box container, some hundreds being released simultaneously.

During the years 1921–1924 the whole bomb position in the Royal Air Force was under review and a future policy was being forged. In this review the Incendiary Bomb played but a small part, and was in fact almost completely neglected. The Ordnance Committee did indeed in 1923 approach the Director of Operational Requirements (Arm) and ask if they were required to investigate incendiary fillings.[2] In his reply D.O.R. (Arm) summarised the advantages and disadvantages of small and large incendiary bombs which may be given briefly as :—[3]

For the small bomb ; spread, increased chance of hitting, no loss through burial in the ground. Against the small bomb ; low penetrative power, small size of inflammatory mass.

For the large bomb ; greater chance of igniting material not readily combustible, greater penetration, spread of molten material. Against the large bomb ; loss of effective load if the case is to be strong enough for effective penetration ; burial in soft ground.

He then went on to assess the comparative value of Incendiary and H.E. bombs, finally asking the Committee to consider trials of both kinds of incendiary bomb, 'without great expense'.

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[1] Another name was Cendite : it was in fact any metallic oxide ground with aluminium.
[2] O.C. Memo. B. 5864.
[3] A.M. File S. 19080.

After further discussion it was decided that the incendiary bomb should be given a low order of priority. It was not desired to allow investigation into incendiary bombs to take precedence over other more important work.

This, in the days of limited expenditure on Armaments, was tantamount to dropping the subject completely, and Ranken's B.I.B., undoubtedly better than anything else of its kind, but virtually untried in war—and from a modern view point, very inefficient—remained the standard R.A.F. incendiary bomb for many more years, despite the very high percentage of bomb failures owing to oblique strikes, due to bad ballistics with its unpredictable trajectory, accentuated by the jostling of the bombs as they left the container.

Viewed in the light of present experience its most serious defect was its trajectory ; it weighed only 5 ounces, its terminal velocity was a few hundred feet per second, and accurate aim was impossible. The only development work during the following years was the constant effort to improve its ballistics by alternately adding more weight to the nose, or more fin surface to the tail. As late as 1934 efforts were still being made to improve the bomb, but with no success. It is important to note that although by then the Design Department was experimenting with a 20 lb. bomb the B.I.B. was still the only incendiary bomb in service.

Strategic employment

The use of incendiary bombs as part load of our bomber force in the Second World War was at all times directly linked with the strategical employment of that force. The latter, with the ever changing situation of the war in Europe, varied from time to time according to the importance attached to each particular objective. Incendiary bombs were mainly used in area attacks on large industrial towns.

At the beginning of the war the High Explosive Bomb was looked upon as the primary weapon for our bomber force, the Incendiary Bomb being regarded as a harassing weapon to be used in relatively small numbers.[1] In 1940, the policy was that 15 per cent. of the total load should be incendiary bombs.[2] The proportion used was approximately 6 per cent.—almost all 4 lb. bombs—the difference being mainly due to conservative use to build up reserves, and varying stowage capacity in the different aircraft employed. In December 1940, Bomber Command, after practical experience, suggested the proportion should be raised to 25 per cent. After careful consideration as to production capacity, reserves, growing supplies of aircraft, etc., the Air Staff agreed to this in January 1941.

By June 1941, the supply of 4 lb. bombs seemed likely to be curtailed owing to a shortage of magnesium, so it was arranged that 50 per cent. of the quota of 25/40 lb. bombs should be covered by 30-pounder production, to create a reserve against possible shortage.[3] The production of 4-pounders improved by August 1941, and in that month an improved system of packing enabled them to be carried 90 per Small Bomb Container (S.B.C.) ; this increased the load carrying capacity by about 50 per cent.

In the following month the principle of the main bombing offensive was reviewed by the Air Staff and it was decided to go for the area attack of industrial towns as soon as possible. From careful study of the results of our raids on

[1] B.C. File BC/S/23746 B. Ops. (26) 1865.
[2] A.M. File S. 4953/1.
[3] The 25/40 lb. bomb was in any case falling into disrepute, and the 30 lb. liquid-filled bomb seemed likely to be the most efficient substitute.

Germany and those of the Luftwaffe on this country, it was evident that though these raids were on about the same scale there was much more destruction in our industrial towns than in theirs ; mainly caused by incendiaries.

There was also conclusive evidence that the Germans were using as much as 60 per cent. incendiaries with an average of 30 per cent., whereas our highest proportion had been 30 per cent. with an average of 15 per cent. Furthermore, the enemy practice was to use a first wave of aircraft carrying all incendiaries then an attack of all high explosive, followed by H.E./Incendiary. Our practice was to dispose the incendiary load among all aircraft. Another point was that it was the number of small incendiary bombs, dropped initially and in the shortest possible time, that produced the greatest damage irrespective of the percentage relationship to the total load. In short, it was apparent that the enemy's policy of incendiarism was by far the most effective.

Accordingly, in October 1941, the Air Staff issued a directive to Bomber Command, the gist of which was that as soon as the weather, and supplies of aircraft, permitted, the policy of large scale incendiary raids and the employment of the technique mentioned should be carried out. Emphasis was laid on the use of the right number of bombs, in the shortest possible time, rather than the proportion of the total load : this was estimated at the time to be 25,000 to 30,000 rising if possible to 1,000,000.[1] As the weight of our attacks increased so did the proportion of incendiaries ; between March and August 1942, the average was 42·5 per cent. Naturally the enemy improved his defences to combat this, and in September 1942 the Air Staff decided that for area attack on primary targets two-thirds of the total load should be incendiary bombs.

During 1943, our own production efforts plus American aid managed to support this policy with devastating effect and on such cities as Hamburg, Bremen, Cologne, Lubeck and the main centres of the Ruhr.[2] Such bombing was kept up until the end of the war, but one other important development should be mentioned ; that of the introduction of incendiary bomb clusters.

In May 1943, photographic interpretation showed that the spead of incendiaries from S.B.C.s was generally far too great, thus minimising the saturation of the main target area. This led to the development of aimable cluster projectiles which were first used in November that year. The value of these was twofold ; they not only improved the concentration of the attack, but, because their size, shape and weight compared favourably with H.E. bombs, no loss of load was incurred with a high percentage of incendiaries.

The 25-40 lb. bomb

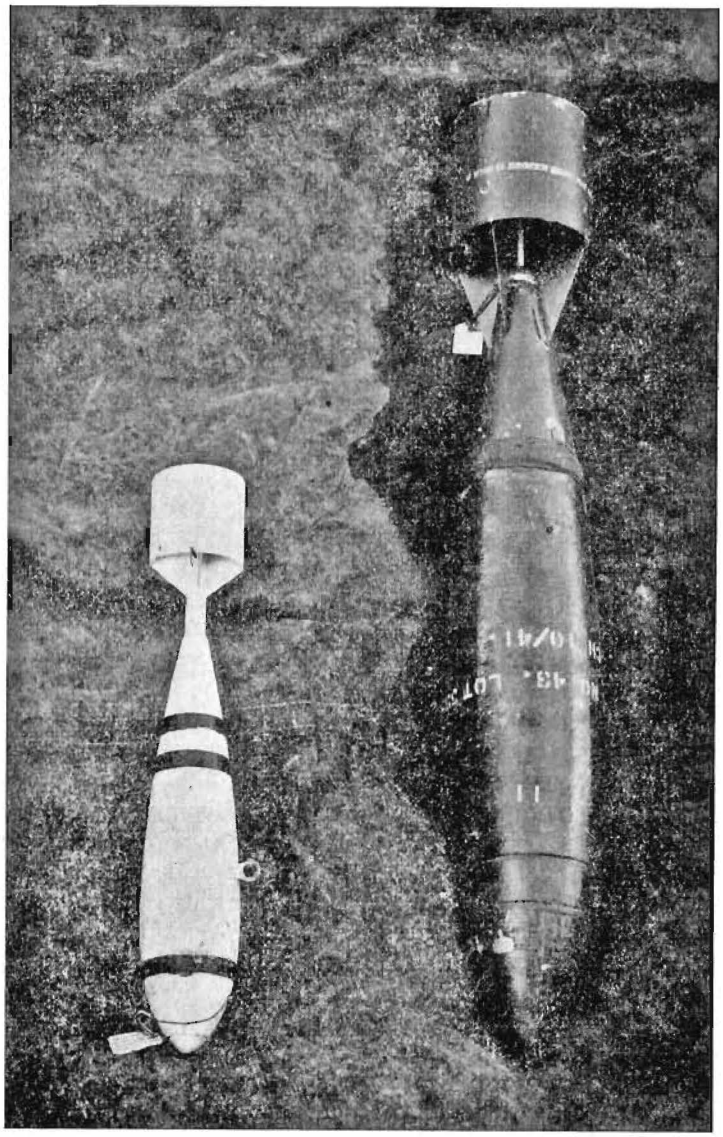
In 1931, following ballistic trials of the B.I.B. at Orfordness, Flying Operations suggested the development of a heavier incendiary bomb and the Assistant Director of Research and Development (Arm.) stated the requirements of the new bomb to be :—

- (*a*) Trajectory similar to that of the practice bomb.
- (*b*) Capable of being released from any height.
- (*c*) To be carried on existing carriers.
- (*d*) To be heavier and more reliable than the B.I.B.

[1] B.C. File BC/S/23746.

[2] For a detailed account of the fire damage, in particular that caused in Hamburg, July–August 1943, *see* Report I.O.(T) 45 Home Office (Civil Defence) January 1946, a translation of a report by the Police President of Hamburg.

The problem of weight, composition and design was put to the Ordnance Committee, who, after consultation with the Chief Superintendent of Research and Development decided to proceed with the design of a bomb weighing about 20 lb. with a thermite filling and stable flight, which in operation was to eject



11½ LB. SMOKE BOMB AND 25 LB. INCENDIARY BOMB

a number of incendiary stars or 'fire-pots.' A.D.R.D.(Arm.) added further details to his requirement:[1] a terminal velocity of not less than 850 f.p.s.; penetration of roofs of warehouses and similar buildings, and oil storage tanks.[2] Alternative fuzes for direct action or delay were also asked for and the Committee agreed to produce six bombs, three of one design and three of another.

[1] O.C. Memos. B. 24099 and B. 24265.

[2] The standard of penetration was a quarter inch mild steel plate from 5,000 feet.

By 1933 the design had not been successfully completed, and in that year, because of the many references in intelligence reports to the use of electron in other countries, particularly Germany, A.D.R.D.(Arm.) suggested that the new bombs might be made, in part, of this alloy.[1] It happened that experiments with electron were then in progress but its use in the new bomb was deferred until the design was complete. By February 1934 trials of electron seem to have been unsuccessful for in that month C.S.R.D. decided against its use, being in favour of magnesium.[2] The bomb as then designed consisted of a steel cylinder with a steel nose filled with thermite. The cylinder contained seven thermite-filled units of about 2 lb. each, with propelling charges between them. On impact these units were thrown out a distance of 10 to 15 yards.

Preliminary static trials of the new bombs at Shoeburynesss gave promising results and ten more were ordered from the ordnance factory for air trials, it being anticipated that these would be ready by the end of 1934. It was however to be June 1935 before they were available for air trials, and in that month six bombs of two types were dropped, one ejecting its incendiary units simultaneously and the other at intervals. Drops were made from 1,000 feet and 500 feet on grassland and shingle and all were successful, but the safety devices were considered unsatisfactory.[3]

When development was still far from being complete, the need for an efficient incendiary bomb suddenly resulted in a hurried order by Air Staff for production of these bombs. In September 1935 the Air Member for Research and Development (Air Vice-Marshal Dowding) wrote to the Chief of Air Staff '. . . We have no stock of incendiary bombs except the Baby Incendiary which is practically useless as it has no ballistics, no penetrative power and very little incendiary effect in comparison with what is possible nowadays. We have now produced in conjunction with Woolwich a bomb of about 20 lb. . . . which contains a number of fire-pots which are ejected from the case after penetration of the objective . . . I suggest we should at once place an order for several thousand 'fire-pots' bombs so that we may have something to use.'

It was decided to order some thousands of the 20 lb. incendiary bomb as an interim measure in the replacement of the B.I.B. although this bomb had neither been developed nor tried out as fully as desirable.

S. of D. was then asked to prepare detailed drawings 'within one week' and Air Ministry declared itself ready to pay for overtime and night work so that these designs could be ready in time. The weight of the bomb was finally settled at 25 lb. and was known henceforth as the '25 lb. incendiary bomb.'

So great was the urgency to have an available stock of the new bombs at the time of the Abyssinian war, that purchase of two thousand Bofors magnesium incendiary bombs for immediate delivery was made in Sweden in November 1935, and as soon as the drawings were received and the manufacture specification prepared for the 25 lb. bomb, arrangements were made for representatives of Messrs. Imperial Chemical Industries Ltd. to meet officials of the Design Department and Air Ministry to discuss production. A second meeting was held at the I.C.I. factory at Roslin in February 1936 between the firm's representatives and A.M. Design and Inspection Departments at which various points of manufacture were discussed—the bakelite moulding of the bomb body, the percentage of

[1] A.M. File S. 30686.
[2] A.M. File S. 32591.
[3] O.C. Memo. B. 29504.

aluminium in the thermite filling, and the construction of the magnesium container (fire-pots). The first 80 bombs were to be ready in three months, after which it was estimated that production could be at the rate of two hundred and fifty per week.[1]

Five thousand bombs were ordered in September 1935 and the design drawings were completed by Woolwich within ten days. The specification was completed a few days later, before the end of September, but three months were spent by the firm (I.C.I.) in 'preliminary investigations' and another three months passed before the various parts of the first hundred bombs could be produced. Full production at two hundred and fifty per week was likely to commence in August 1936 nearly a year after the Air Staff decision, with no real guarantee even then that the bombs would be satisfactory.

In spite of manufacturing difficulties and constant correspondence, often on minor points, and numerous alterations to the original specification, the first trial bombs were dropped at Martlesham Heath on 24 June 1936. Their performance was generally satisfactory: trajectory appeared good and the firepots were well ejected. No test was made for incendiary effect, indeed no suitable target was available for such a test.

The trials did however suggest various small modifications which after approval by S. of D. were communicated to I.C.I. Ltd. and by July 1936 a further twenty bombs were ready for test at Roslin. These, apart from minor failures, were successfully tested on the 16th of that month, but by that time the inevitable demand for more modifications had begun. The bomb as then shaped was suitable for carriage on the light series carrier but not in the newly designed 250 lb. small bomb container (S.B.C.). A new filling for the firepots was required by A.M.R.D. occasioning large quantities of magnesium and barium nitrate, supply of which was uncertain, and in any case the new mixture presented additional safety and storage problems. The bomb shape was therefore re-designed and it was decided that future orders should be of the new shape, with the original thermite filling.[2] The order for five thousand was to stand.

In October 1936 ballistic trials at Orfordness with dummy bombs carried in S.B.C.s confirmed that the new shape was suitable. By February 1937 subcontracts for various bomb parts had been placed with seven engineering firms, and in March three hundred completed bombs had been sent for trial at Martlesham by I.C.I.

The bomb was introduced into the Service as the 25 lb. Mark I in August 1937 and by the end of that year full production had commenced, though not without difficulty, for in November filling by Messrs. I.C.I. had been stopped, owing to the discovery of faulty welding between the nose and the central tube of the bomb, and some cracking of the firepot casings during trials at Martlesham Heath. The welding difficulties were solved by more careful manufacture, and the split firepot problem was put to the Ordnance Committee. After consultation with the Aeronautical Inspection Department it was decided that split containers would not seriously affect the operation of the bomb, and they might be used provided the split was not more than one inch long, and the attention of the firm was drawn to the defect.

During the first months of 1938, extensive ballistic trials of the production bomb were carried out at A. & A.E.E. where the bombs were released singly and

[1] A.M. File S. 30686.
[2] A.M. File S. 30686/2.

in salvo. Forty-eight bombs were dropped from heights of 10,000 feet to 2,500 feet at an airspeed of 190 f.p.s. : the single releases were satisfactory, salvoes of four bombs each had a 'straggler' which fell wide of the others, but generally the bombs were considered satisfactory for both kinds of release.

In May 1938 following successful trials at the I.C.I. factory, a new magnesium alloy for the firepot cases was adopted for future use. During the first half of that year some concern was felt by the Director of Armament Development at the results of the proof of production bombs, as differences in burning qualities of the magnesium casings made by various firms had been observed. Accordingly a very thorough investigation was made by C.S.R.D. who concluded that 'all the magnesium alloys which have been employed for the manufacture of bombs will give a good incendiary effect.'[1]

The bomb was rushed into production in 1936 and its consequent history is one long series of small manufacturing difficulties, too numerous to be given in detail. The remarkable feature in a complicated story is that the bomb was tested for every quality except its ability to start a fire. Its ballistics were calculated, its penetrative power was measured, endless correspondence passed between the Air Ministry, Ordnance Committee, Woolwich, Messrs. I.C.I. Ltd., and a dozen contractors, on small comparatively unimportant details such as the right material for sticking brown paper to the central tube, and the presence of a minute quantity of calcium in the alloy case, but no bomb was dropped on a house, factory, or oil storage area.

Eventually in April 1939 the bomb was tested against a disused filling factory and power station near Gretna Green. A full report is contained in the reference quoted but the section dealing with 25 lb.[2] incendiary bombs may be reproduced here :—

> 'One hundred and fifty-six of these were dropped from between 3,000 and 6,000 feet at a true airspeed of 140 m.p.h. Of three hits obtained on the power-house only one was on the roof. It penetrated this, and a 4-inch concrete floor, broke up and failed to ignite. Of thirty-two bombs released from 250 feet, six hit the roof of the annexe, broke up and failed ; the seventh stuck in the outer wall and burnt correctly.'

The resulting recommendation of the Ordnance Board was that the bomb could not be regarded as suitable for a land target from any height.[3]

As a result of this unfortunate and belated discovery the Director of Operational Requirements (D.O.R.) wrote on 26 July 1939 to D.Arm.D. :—[4]

> 'Possible modifications to improve the bomb were discussed with members of D.Arm.D.'s staff and modifications are being put in hand immediately to try and obtain a better performance. If this is successful, existing stocks will be modified. It is clear, however, that no modification will make this bomb entirely satisfactory, and a new type of 25 lb. incendiary bomb will be required.'

The existing stock numbered some half million. Design work on the new bomb was to begin at once and its requirements were :—

(a) It need not be of the multiple unit type ; in fact, a single unit would probably be preferable.

[1] O.C. Memo. 63/38.
[2] O.B. Report No. 2/39 (Gretna Green Trials).
[3] The Ordnance 'Committee' became the 'Board' on 1 January 1939.
[4] A.M. File S. 1633.

(*b*) It must penetrate a light roof and 4 inches of concrete from 6,000 feet.

(*c*) It must be capable of carriage in S.B.C.s.

(*d*) The T.V. must be at least 850 f.p.s.

D.O.R. recommended the work to have P.X. priority.

At this time there was a deficiency in the total to meet Air Staff requirements of some 229,000, but D.O.R.'s first action was to suspend all further production of the bomb until some suitable modification had been designed to strengthen the bomb. Immediate efforts were made to achieve this, particularly at the tail, the weakness there having been revealed on land target trials at Gretna and Porton. The Design Department prepared plans of a suggestion to reinforce the tail with a metal ring. Fifty modified bombs were quickly produced and tested at Gretna in July 1939, but with no success. The problem was therefore to dispose of in the most economical way the 660,000 bombs which had been manufactured.

Since the beginning of 1939, a requirement for an incendiary bomb to start forest fires had existed, and had been met, with limited success, by the employment of the 25 lb. bomb with a parachute. A maximum of 25,000 of these bombs was required by March 1940, and that number of obsolete 25 lb. bombs was thus usefully absorbed.[1]

Two further efforts were then made to utilise the valuable material locked up in the remaining bombs. The first was in strengthening the bomb by adding a heavy steel nose which brought the weight up to 40 lb.; the second was a modification without adding to the weight, in the fitting of an ' all-ways ' nose pistol and a light snap-on tail.

Designs for the 25/40 lb. bomb were hurried through by C.S.R.D. and a small number manufactured at short notice. Unsuccessful trials were held at Porton in September 1939, and after further modifications somewhat more success was obtained in the following month, although still far from being completely satisfactory. Still further strengthening was applied bringing the weight up to 41½ lb., and a final test against a brick building target at Faversham (Kent) gave very satisfactory results.

As a result the Ordnance Board recommended the adoption of the modified bomb and orders for 500,000 were placed. Special machinery was set up by I.C.I., Ltd., to recover the magnesium firepots from the now discarded 25 lb. bombs. Meanwhile the second of the experiments to embody a more simple and less expensive modification in the 25 lb. bomb had been made, resulting in a Mark II pattern,[2] the later history of which type will be taken up again elsewhere in this chapter; it is necessary now to turn to another incendiary bomb which had meanwhile been developed.

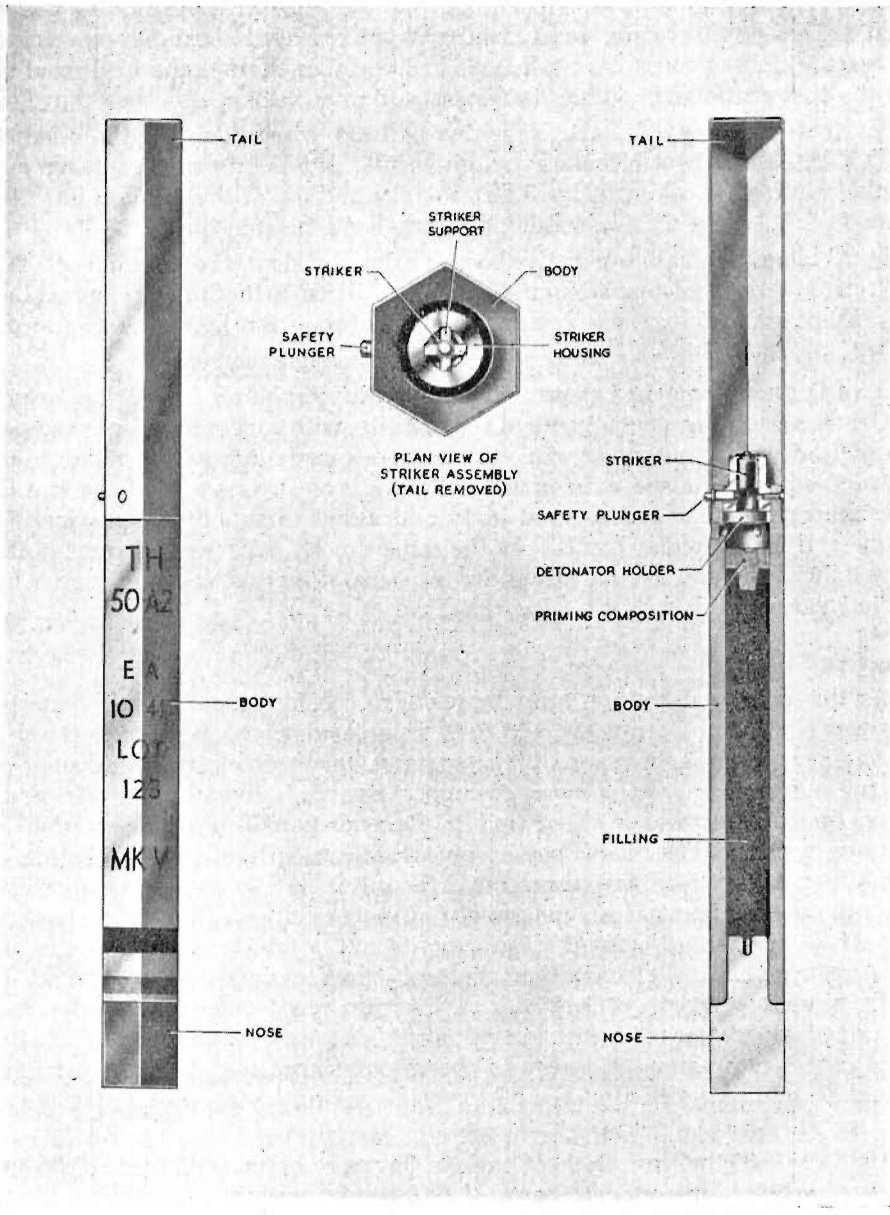
Development of the 4 lb. incendiary bomb

In August 1934, the Director of Technical Development in dealing with the shortcomings of the B.I.B. wrote to the Operational Requirements (O.R.) branch of the Air Ministry:—[3]

> ' Do you agree that we should design a 1 lb. or 2 lb. incendiary bomb of Electron? The 5 oz. bomb seems too small to start fires unless the conditions are very favourable. Trials might well show that the 2 lb. bomb is

[1] The problem of creating forest fires is discussed later in this chapter. A.M. File S. 48336.
[2] A.M. File S. 55110.
[3] A.M. File S. 32591.

large enough for many conditions, and if this is so, ten 2 lb. bombs might well be a more dangerous weapon than the one 20 lb. bomb we are developing, which is complicated and likely to be difficult to make in quantities.'[1]



4 LB. INCENDIARY BOMB, MARK V

Tentative designs were prepared by the incendiary bomb branch of A.D.R.D.(Arm.) in conjunction with the Armament Department of the Royal Aircraft Establishment, but little progress was made up to May 1935 when

[1] The 25 lb. bomb already described. (Prophetic words !)

drawings of these designs were sent to R.A.E. for ballistic tests of models. These early drawings show a rough streamline shape with pointed or hemispherical nose, and in one instance a drum type tail.[1] From wind tunnel experiments R.A.E. finally suggested a cylindrical bomb with a bluff nose for greatest stability. In September 1935, however, A.D.R.D.(Arm.) suggested that a hexagonal, square, or triangular shape might be best for economical stowage. Subsequent tests at R.A.E. in December showed the hexagonal to be the best shape and to give the highest terminal velocity.

Even so, there was, at the beginning of 1936, some doubt in the mind of A.D.R.D.(Arm.) about incendiary requirements, and he prepared a summary of of the position for comment by O.R. For the purpose of this account only the paragraph relating to a new small incendiary bomb need be quoted :—

> ' Should a small penetrative bomb be developed ? If so, a bomb of 3 lb., made largely of magnesium alloy and filled with thermite, cylindrical in shape with pointed nose, terminal velocity of about 800 f.p.s., was suggested.'

O.R.'s answer to this was ' Yes, at the earliest possible moment.'

S. of D. was approached about the design of the new bomb, ' on high priority,' and was asked to consider a bomb of about 3½ lb., with a cylindrical or hexagonal body, lead nose, tinned plate tail, the body of magnesium with a filling to be decided on after consultation with C.S.R.D. S. of D. was told of the R.A.E. recommendation for a hexagonal body and asked to submit designs for this shape and for a circular bomb. At the same time R.A.E. was informed of the new dimensions and asked to consider a means of increasing bomb scatter by having various nose shapes to alter the drag.

Electron

At this point a digression must be made to consider the choice of material for the new bomb. In 1923, C.S.R.D. completed an analysis of a German incendiary bomb and reported that it was made of electron, an alloy of magnesium and zinc, with traces of copper, iron and aluminium.[2] Ten years later the incident was recalled and in December 1933 a demonstration of various types of incendiary bombs given by C.S.R.D. included an electron ' bomb ' : a tube filled with compressed thermite. At the same time a general interest in the manufacture and supply of magnesium was awakened both in the Air Ministry and Admiralty, an experimental production plant was set up at Rainham, and an examination made of deposits of Dolomite, from which magnesium is derived, in Derbyshire. Electron was found to have what was described as ' remarkable incendiary power,' not easily extinguished ; it did not burn steadily but at intervals threw out showers of burning particles. C.S.R.D. recommended that the 3½ lb. bomb should be largely constructed of this metal.

By July 1936, ballistic trials of various shapes recommended by S. of D. had been completed with model bombs at Orfordness, with the conclusion that a ' bluff ' (flat-nosed) bomb of hexagon section was the truly satisfactory model. Its T.V. was calculated at 400 f.p.s. and the weight at about 4 lb., and in August that year an experimental order for 200 was placed with I.C.I., Ltd. In this early design the safety device was clumsy and unsatisfactory, as a plunger had to be removed by hand from each bomb before loading. An improvement

[1] A.M. File S. 32591.

[2] A type which was used in the 1914–1918 war.

consisting of a horizontal spring-loaded plunger, retained in each bomb by its neighbour in the bundle, and which came out—thus arming the bomb—when the bombs separated in release, was included in a batch of bombs tested at Orfordness in September 1936.[1]

In this trial, which was very successful, experimental bombs differing in construction and filling were dropped from heights of 10,000 feet to 500 feet on to concrete, grassland and shingle, singly and in batches from a container. Ballistics were satisfactory and all bombs burnt, a film of the bombs leaving the container showed that they did not jostle ; row after row fell evenly.

Some small amendments to the design were suggested, and another experimental order for 200 bombs was made. It is of interest that as well as the air trials static trials were done by I.C.I., Ltd., during which the effect of the final bomb position on combustion was noted. Those finishing upright burned right out ; for those tilted nose down the chances were good, but with nose up, much less.[2]

On 20 October 1936, an order for 4½ million bombs was placed, and, by the beginning of November a provisional specification had been prepared. Much latitude was given to the manufacturers ; the bodies might be either die-cast or extruded, and the fillings either pressed in or inserted in the form of pellets. The new bomb was to be called ' Bomb, Incendiary, Aircraft, 4 lb., Mark I.'

Containers

Mention of the containers for these bombs is necessary at this stage. For ease and rapidity of loading they were packed in a tinned plate box—twenty per box—with a tear-off lid. The box, placed in a compartment of the small bomb container, then had the lid ripped off and the bombs were secured in position by a drop bar. Being hexagonal the bombs could not fill the whole of the box, and packing pieces had to be used. Trials at Orfordness in January 1937, showed that the bomb scatter was far better with fixed packing pieces as compared with loose ones, and this method of box construction was permanently adopted.

4 lb. bomb development (continued)

As might be expected with a bomb whose conception and development had occupied so short a time, various manufacturing difficulties were met with in the early stages of production, and the method of dealing with these is worthy of note. Representatives of the manufacturers concerned were called together at the Air Ministry, and the various points discussed with the Director of Aircraft Production and a representative of A.I.D. Most of the points raised required only small tolerance concessions, and solutions to the problems seem to have presented few difficulties. No major ' hold up ' in production occurred, and by the end of March 1937 the first 220 production bombs had been sent to Martlesham Heath for test.

Included in this first batch of bombs were two lots of twenty each, for special test. Their fillings were experimental, containing respectively fine and coarse aluminium powder in the order of 50/50 and 40/60. These ingredients, used in the filling of the incendiary pellets, were on trial because the normal 100 per cent. fine grade powder added to the time of manufacture and was suspected of being somewhat dangerous to use. Before the trials commenced

[1] A.M. File S. 32591.
[2] A.M. File S. 38871.

a further twenty experimental bombs were added to those already at Martlesham.[1] These had been produced as a result of comparison tests between the British 4 lb. bomb and the Swedish ' Bofors ' incendiary bomb of similar weight with greater magnesium content. This latest experimental 4 lb. type had its electron case bored out to the maximum limit allowed to permit the introduction of more magnesium.

All two hundred and forty bombs were dropped between 15 April and 5 May, with only one failure, and no noticeable difference was observed between the bombs of various fillings (it should be noted here that all bombs appeared to be the same ; no actual incendiary tests were made). Ballistic inaccuracy was noted ; with each batch released a practice bomb was dropped, the mean point of impact varied considerably with that of the practice bomb, and one of the conclusions of the trial was :—[2]

> 'Any accurate aiming of these bombs at heights of 10,000 feet or above is impossible without a special sight, and even then it is doubted if consistent results could be obtained.'

By the beginning of June 1937, four thousand bombs had been produced and filled, of which total twenty per thousand were sent to A. & A.E.E. for dropping tests for operation and spread. These tests revealed a fault in the bomb resulting in a number of explosions, and this failure was referred to C.S.R.D. for investigation. Various other modifications were recommended and samples prepared for test, and as a result a new filling procedure was drawn up.[3]

Some 20,000 bombs with the original filling were by then in stock, and, being under suspicion, they were allotted for training purposes, except 2,000 which were sent for operational use in India. In September 1937, the bomb was officially introduced into the Service. Having got this important bomb into service the Air Staff began to enquire into its capabilities. Although no conclusive trials of its incendiary value had been staged, the question of its penetrative powers was first raised in a consultation with the Ordnance Committee. The Committee naturally recommended dropping trials on representative targets, but no such targets were available so substitute trials were made in which shot, weighted and modelled similar to the bomb, was fired at 400 f.p.s. striking velocity at representative roof targets. From these investigations the Committee formed the opinion that the bomb would penetrate ordinary roofs, reach the top floor and probably two or three floors below.[4] The Air Staff accepted this view and ruled that no further trials were necessary.

In July 1940, General Von Schroeder, President of the Reich A.R.P. Services, wrote in *Deutsche Algemeine Zeitung* :—' It has been observed that the incendiary bombs used by the English have a greater power of penetration than is usually presumed. Experience has taught that one must reckon that the bombs penetrate, not only to the floor below the roof but even cause fires in flats below the attics.'

The 4 lb. bomb, Type ' E '

The first important modification to the new bomb was the inclusion of an explosive pellet to deter approach during burning. In 1937, the Ordnance Committee investigated the alternative suggestions by A.D.R.D.(Arm.) of a

[1] A. & A.E.E. Report M/Arm. 486/1.
[2] A. & A.E.E. Report M/Arm. 475/6, 11 May 1937.
[3] O.C. Memos. B. 32591 and B. 35075.
[4] O.C. Memos. B. 33752 and B. 34447.

small bursting charge or a pellet to produce tear or sneezing gas.[1] The chemical suggestion was eventually ruled out as being insufficient and trials with explosive charges were put in hand, the principle being to give the explosion late in the burning time of the bomb and after its first intensive incendiary outburst was expended.

In March 1938, D.O.R. agreed to the inclusion of an explosive pellet, providing it did not interfere with the production of Mark I bombs, and after some delay the method of inserting the charge—10 grammes of gunpowder in a paper container—was settled as being in the bomb body near the nose and one hundred bombs were ordered for trial.[2]

Following promising trials at Porton on 3 January 1939 instructions were issued to the firm to go ahead with their preparations for making the pellets, and for the conversion of 20 per cent. of the Mark I bombs already filled or being filled. The total number to be thus converted amounted to approximately 500,000, the letter ' E ' being used to describe the bomb thus modified. By the end of 1939 the production of both types amounted to 60,000 per week, of which 10,000 were of the ' E ' type. Stocks of these were three million Mark I and two million mixed Marks I and IE. In the Gretna Green trials of April 1939 the Mark IE bomb was very successful.[3] The only failure of a burning bomb to explode was in one that came to rest so that the molten magnesium ran away from the nose of the bomb ; a state of affairs likely to be rare. The explosions in successful bombs occurred from 2 to 10 minutes after impact. As a result of this trial the Ordnance Board concluded that no further experiment was necessary.

The Mark I bomb (conclusion)

We now return to the story of this bomb which by the latter part of 1937 was in full production. In December of that year, D.Arm.D. decided that storage and rough usage trials were necessary and asked the Ordnance Board to undertake them.[4] During various trials it had been noticeable that bomb bodies from four different firms had displayed differences in burning, and the Board were asked to test specimens from each manufacturer. The tests were completed by July 1938, bombs from all the manufacturers being proved satisfactory.[5] In the same month C.S.R.D. completed his examination of the various magnesium castings used for the bomb bodies and found that all gave satisfactory results. He recommended finally an alloy consisting of :—[6]

Aluminium	not more than 5 per cent.
Zinc	not more than 0·5 per cent.
Manganese	not more than 0·3 per cent.
Calcium	nil.

the remainder magnesium, with not more than 0·5 per cent. of impurities.

[1] O.C. Memos. B. 33752 and B. 35739.
[2] A.M. File S. 37546.
[3] O.B. Report 2/39.
[4] The trial involved placing the bombs in a machine and jolting them for six hours—two hours each on end, side, and bottom ; the jolts were sixty a minute through $1\frac{5}{8}$ inches. After jolting the usual procedure was to try half the bombs by ignition, and to break down the remainder for examination.
[5] O.B. Memo. B. 36252/37.
[6] O.B. Memo. 631.

No other important modification was made to this highly successful bomb. Other Marks of 4 lb. bombs were yet to appear, but these were in the main necessary because of a shortage of magnesium, and will be mentioned later. As far as the period under review is concerned (1931–39), this account ends with the Royal Air Force being in a far better position regarding incendiary bombs than had seemed probable a few years before, thanks to the efficient and willing co-operation in design and production between the service departments and civilian firms concerned.

The 25/40 lb. bomb, Mark II

Earlier in this account we had left the history of this type at the stage (1939) when efforts were being made to improve upon the unsatisfactory Mark I bomb. It has already been related how the weight of the strengthened 25 lb. bomb had been increased to about 40 lb. and half a million of these had been ordered. Let us now consider the Mark II type.

The objects of the modifications in this mark were to improve the efficiency of the bomb by strengthening its construction, and by fitting a '3-ways' pistol designed at Woolwich. This pistol was intended to increase the safety of the aircraft and crew, and of the armourers handling the bomb. Original safety had depended entirely on a shear wire which broke after a fall of only 3 feet on to concrete; the new pistol was fitted with an air-arming device requiring a fall of some 50 feet before becoming 'live'. This new bomb was tested on the hard target at Porton in August 1940 and gave moderately satisfactory results; approximately 50 per cent. of the bombs were successful.[1]

By that time one million of the 40 lb. bombs had been ordered and production was expected to begin in December 1940—difficulties in obtaining the necessary steel had been met—and at least a further month would elapse before filling could commence. On the other hand the Mark II bombs could probably be in service within a month of orders being placed. The question therefore arose, which of these two it would be best to accept; if the Mark II, then orders to cancel production of the larger bomb would have to be given immediately. A meeting of representatives of D.Arm.D., D.Arm.P., and D.O.R. discussed this question at the Ministry of Aircraft Production in October 1940.

There were now three suggested ways in which the 660,000 useless original 25 lb. bombs might be used up:—

(*a*) They could be converted to the 40 lb. type with 3-way pistol; this would mean a large consumption of steel, a good deal of machinery, and a reduction in the number of bombs which could be carried; about 80 per cent. success might be expected.

(*b*) They could be modified by the inclusion of a 3-way pistol, air-armed, and a spring-on-tail. This required little labour or material, and more could be carried. About 70 per cent. success could be expected.

(*c*) The bomb could be fitted with a parachute and used against targets not requiring penetration (forests and soft targets generally).

Apart from questions of efficiency the meeting discussed the time which would elapse before any of the various bombs were produced. With modification (*a*) fuze production could not be expected before March 1941; components for (*b*) could be ready in a few weeks, and production of the complete bomb

[1] M.A.P. File S.B. 11411.

could then commence.[1] On these and economic grounds the meeting decided to recommend to D.O.R. that the 40 lb. order should be cancelled in favour of modifications (*b*) and (*c*). The matter was then referred to the Assistant Chief of Air Staff (T.R.) who ruled that the order for a hundred thousand 40 lb. bombs must proceed, and that the remaining stock of obsolete 25 lb. bombs should be converted to the Mark II and parachute patterns.

By June 1941, however, A.C.A.S.(T) had authorised the abandonment of the 40 lb. bomb on the advice of various departments who considered it both inefficient and uneconomical. One opinion was :—[2] ' It seems to be a very bad business to carry all the way to Germany 35 lb. of good steel in order to deliver 5 lb. of magnesium. Apart from the steel which is presented to the Germans the fabrication of the bomb is obviously a lengthy and expensive business.' It should be borne in mind that the 40 lb. type was really never more than a stop-gap to meet Air Staff requirements for a penetrative incendiary bomb, and to use up some of the existing firepots from the useless 25 lb. type.

Regarding the second attempt to save waste of incendiary material and supply a more efficient bomb, i.e. the 25 lb. Mark II, this was too, after many more trials, abandoned.[3] It was unsuitable for anything but low height attacks against non-resistant targets ; against other targets from high-level it broke up and would not ignite, and was withdrawn from service early in 1942. Approximately 20,000 of these bombs had been used in operations by Bomber Command, and the remainder (approximately 400,000)—except for a few Mark I's retained for use as parachute-bombs—were collected and reduced to scrap. The labour involved was immense, and no attempt could be made to recover the filling, so the bombs were fired and only steel bodies and tails saved.[4] The third alternative for using up the Mark I bombs suffered a like fate. In 1942 all further work on 25 lb. parachute bombs was abandoned.

The 4 lb. bomb, Marks II, III and IV

To return to the story of this successful bomb ; a Mark II pattern was introduced at the beginning of 1940, which differed from the Mark I only in having a slightly shortened tail to enable the bomb to fit a different size S.B.C. container lining.

In 1941 the supply of magnesium became increasingly difficult while the demand for incendiary bombs was ever on the increase, and it became necessary to effect some economy. In consequence a Mark III design was produced in which the bore of the magnesium body was increased from seven-eighth inch to one inch, resulting in a saving of two and a half ounces of magnesium per bomb, with, however, a corresponding decrease in the bomb's efficiency. During 1941 a series of trials at the Forest Products Research Laboratory, Princes Risborough, had established that the efficiency of the bomb was proportional to the quantity of magnesium in it. Thus the original Mark I with its 1 lb. 9½ oz. of that alloy was the most efficient of the whole series. It was, however, quite impossible to meet Air Staff's requirements without modification and eventually the Mark IV bomb was designed, to give a saving of 8½ oz. of magnesium

[1] M.A.P. File S.B. 2379.
[2] A.M. File S. 4953/1.
[3] M.A.P. File S.B. 1411/4.
[4] A.M. File S. 66241.

compared with the Mark I. The trials at Princes Risborough had led to the conclusion that the minimum amount which could be accepted for efficiency was 1 lb.; the Mark IV bomb contained 1 lb. 1 oz.[1]

The additional saving thus made was effected by a redesign of the tail. In the original design the striker mechanism was contained in the tail and was surrounded by magnesium. (In fact this often failed to ignite and was wasted.) In the new design the striker mechanism was transferred to the bomb body, having a tail of tinned iron sheet screwed to the body. At the same time the whole striker device was simplified and made entirely of steel so that introduction could be accelerated.

Trials of the new bomb at the I.C.I. Ltd. factory and A. & A.E.E. in July and August 1941 were very successful and proved the bomb to be satisfactory for service use, the only criticism being that the safety shear wire gave insufficient safety in loading. To overcome this a thin cruciform brass washer was employed in place of the shear wire and found satisfactory.

On 28 August 1941 A.C.A.S.(T) approved the introduction of the Mark IV bomb into service, remarking[2]—' I think however that with this mark of 4 lb. bomb we have reached the limit to which we can go in reducing the magnesium content of the bomb, and I think this must now be recognised by the Ministry of Supply.'

This decision was regarded as final, and although D.Arm.P. wrote urgently to D.Arm.D. that a further saving of magnesium was necessary, the latter, supported by Air Staff refused any further concession, and no more major alterations were done to the Mark IV pattern. By September 1942 the bomb was in full production and trials of production bombs had been successfully completed by A. & A.E.E.[3]; in particular for stability in salvo release from small bomb containers and for safety after dropping a short distance (e.g. accidently while loading).

A point of great interest arose during the latter part of 1942, by which time the 4 lb. bomb was being manufactured and filled in the U.S.A. For the latter process the Americans had designed a rotary filling machine. The use of such a machine in this country was suggested, and a full description of it was obtained from the makers by the British Air Commission in Washington.[4] D.Arm.D. and D.Arm.P. together with I.C.I., Ltd., considered the question carefully and decided not to adopt the machine method.

The decision received apparent justification later, in April 1943, when one hundred and eighty British made and one hundred and eighty American made bombs were tested under similar conditions on the Braid Fell target. One hundred and eleven American bombs failed as against nineteen British.

The 4 lb. ' X ' bomb

It will be remembered that early in the history of the 4 lb. bomb an ' E ' type was successfully produced in which a small gunpowder pellet caused a mild explosion as a deterrent to enthusiastic fire-fighters. By the end of 1940, however, it was doubted whether this had sufficient deterrent effect to offset the disadvantage that the explosion would often destroy the incendiary value of the bomb, and even extinguish a fire already started.

[1] O.B. Proc. 13630.
[2] A.M. File C.S. 10168.
[3] O.B. Proc. 15402/42.
[4] M.A.P. File S.B. 19848.

The problem then was, whether to abolish the small explosion entirely, or to increase it by the substitution of H.E. for gunpowder, to lethal proportions. After discussions between representatives of Air Staff and M.A.P. and authorities of the London Fire Force a lethal explosive charge was decided on. Accordingly in December 1940, D.Arm.D. requested the Ordnance Board to examine the filling and burning problem, but not the design of the bomb; this was to be done by D.Arm.D.'s staff in conjunction with a manufacturer.[1] In February 1941 D.Arm.D., on the advice of C.S.R.D., indicated in a letter to the Board that the substitution of H.E. for gunpowder would be unsatisfactory; the amount would be insignificant and production difficult.[2] An entirely new design—based on trials with the German 1 kilo bomb—was suggested, in which a nose fuze would be fitted and the H.E. contained in a steel gaine screwed to the tail.

Progress on the new design was slow, C.S.D. having great trouble with the nose fuze. At a meeting at M.A.P. in August 1941, every possible reason for not proceeding with development of the 'X' bomb was put forward, including a possible shortage of composition explosive (Tetryl). At this meeting the Vice President (Air) Ordnance Board was in the chair, and D.Arm.D., D.O.R. and C.S.D. were represented. After the meeting the members paid a visit to H.Q. London Fire Force where they were told that explosive in incendiary bombs was no deterrent to determined fire-fighters.

Under pressure from the Air Staff, however, an entirely new design being quickly produced by C.S.R.D.[3] and the Chief Superintendent of Armament Design,[4] and by 20 February a development order of 2,400 bombs had been manufactured and successfully tested on the Braid Fell target.

Outwardly the new bomb resembled the standard 4 lb. bomb but part of the igniting composition near the nose was replaced by delay pellets (delays of two minutes and four minutes were available). A steel nose containing a detonator and a small charge of Tetryl was fitted. On ignition, and after the requisite delay, the steel nose was shattered, scattering fragments which were lethal at short distances. Further successful trials were completed on 12 March and shortly after this arrangements were made to put the bombs into production. For this, I.C.I. Ltd. required extensive new buildings and plants, which, if provided quickly, would permit full scale filling to commence within six months: meanwhile production could continue at the rate of from 2,000 to 3,000 per month.

Having been designed and brought into service in remarkably short time the bomb was capable of improvement at leisure. Tests by C.S.R.D. had shown that fragmentation was coarse with poor penetration, and could be improved by a re-design of the explosive charge, both in size and substance.[5] The use of T.N.T. or Pentolite instead of C.E. was suggested.

Further troubles developed during proof of the first production bombs, the worst of which was the refusal of the C.E. charge to detonate.[6] Research by C.S.R.D. led to discovery that heat conducted along the nose from the incendiary part of the bomb ignited the C.E. prematurely, after which it burned

[1] M.A.P. File S.B. 4183.
[2] O.B. Proc. 10551/41.
[3] O.B. Proc. 16320.
[4] C.S.A.D., formerly C.S.D., Chief Superintendent of Design.
[5] C.S.R.D. Exp. Report 115/42.
[6] O.B. Proc. 18510.

quietly without detonation. Another trouble observed in proof was partial detonation, attributed by I.C.I. Ltd. to pressure—generated in burning—displacing the delay and H.E. pellets. C.S.R.D. therefore recommended the development of a bomb, designed to eliminate if possible these troubles, mainly by the insulation of the charge from premature heating.

On 30 May 1942, the 4 lb. 'X' bomb had been extensively used on a raid on Cologne, apparently with great success, but the Germans too were using a 1 kilo explosive incendiary bomb which appeared to be more efficient. A comparative test of the two types was to follow, leading to increase in the H.E. content of the British bomb and many other improvements, but meanwhile other types of incendiary bombs were being developed and so for the time being we will leave the 4 lb. 'X'.

The 30 lb. liquid filled incendiary bomb, Marks I, II, III and IV

Between 1937 and 1940, the need for a liquid filled incendiary bomb, chiefly for the ignition of oil from burst storage tanks, had led to experiments with the case of the 30 lb. L.C. bomb designed for a chemical filling. These efforts were largely abortive, but in November 1940, three factors decided the serious development of such a bomb :—

(*a*) The growing shortage of magnesium.

(*b*) The failure of the 25 lb. bomb.

(*c*) The existence of some quarter million 30 lb. cases not required for chemical filling.

The bomb-case was available but the choice of the most suitable filling called for much research and experiment, and this was done by C.S.R.D's. department in conjunction with Messrs. Albright and Wilson, Ltd., Birmingham.

Previous experience had shown that petrol or benzol alone was useless as a filling ; the ideal incendiary liquid must be slow burning—most targets need contact of some duration before being well ignited—and moderately viscous so that loss by spray and evaporation is reduced. A solution of crude rubber and benzol in the proportion of 55 grms of rubber per litre of benzol proved effective, except that when used with the standard gunpowder burster full ignition could not be obtained.

Accordingly some experimental fillings were devised which in the main concerned the use of phosphorus as an aid to ignition. In each case a quantity of phosphorus was filled in the nose of the bomb, around the burster, before the benzol-rubber solution. One other expedient, the use of magnesium powder as well as gunpowder in the burster—was proposed, and four trial fillings were made up as follows :[1]

(*a*) 1½ lb. 'liquid phosphorus.'
6 lb. rubber solution.

(*b*) 1½ lb. white phosphorus.
6½ lb. rubber solution.

(*c*) 15 grammes magnesium, grade 3.
6¾ lb. rubber solution.

(*d*) 1 lb. Red phosphorus.
5 lb. rubber solution.

[1] A.M. File C.S. 13263.

These fillings were first tested 29 November 1940, at Messrs. Albright and Wilson's factory at Kidderminster and were very successful. Several bombs of each type were fired statically, the 'liquid phosphorus' being best, white phosphorus second best, and not much to choose between the other two. The various experts present at the trial decided to go ahead with dropping trials of the first two types and D.O.R., who was represented, soon arranged with D. Arm. D. for development to go ahead on high priority.

On 23 December 1940, forty-eight bombs were dropped on hard and soft targets by A. and A.E.E. and twenty others were fired at rest.[1] These trials proved the bomb to be a reliable fire producer and that white phosphorus was superior to the liquid type. The A. and A.E.E. report was very favourable indeed, and three days later a realistic trial in a damaged small house in Barnes, stacked with wood, hessian rags, etc., to represent furniture, proved even more the incendiary value of the bomb.

Early in January 1941, the 30 lb. bomb was put forward for Air Staff approval, and after considerable discussion on H.E./Incendiary policy, and whether the 25/40 lb. magnesium bomb was yet likely to prove its worth, D.C.A.S. agreed to a token order for 10,000 bombs; any further production was to be delayed until it was definitely established that the 25/40 lb. bomb was unsatisfactory, or that magnesium supplies would not permit its production in addition to the 4 lb. size.[2]

The abandonment of the latter bomb in June 1941, and other reasons, *e.g.*, magnesium supplies, and production facilities for 30 lb. L.C. (chemical warfare) bombs, led to a production order for 400,000 incendiary 30 lb. bombs, and by July of that year production was at the rate of 4,000—5,000 per week.[3] The Mark I employed the same fuze (No. 38) as the 30 lb. L.C. bomb, except that the delay pellet was removed and replaced by gunpowder. It was a penetrative bomb intended for use against hard targets where the best possible aiming was required, and was carried in the small bomb container (8 per S.B.C.). On impact the fuze ignited a burster, blowing off the tail and tail plate, ejecting and igniting the charge which dispersed over an area of some 60 by 40 yards.

During early production a change in filling materials was made, liquid phosphorus being used until plant for rapid filling with white phosphorus could be installed, and petrol substituted for benzol. Benzol had a serious toxic effect on the filling staff and a replacement was necessary, although the change over meant the use of rather more rubber to give the same viscosity. By the end of 1941, the Mark I was in full production, in use by Bomber Command, and declared obsolescent in favour of a Mark II design.

Early in 1941, while the Mark I bomb was in course of development, it was evident that if quantity production was eventually required some simplification in construction was desirable. In fact before the first production order for Mark I bombs was given, design work for a different bomb body was being done by the incendiary bomb branch of M.A.P. in conjunction with Messrs. Luxfer Ltd., Harlesden. Between them they produced a design of much simpler manufacture, several machined parts being replaced by pressings, which

[1] A.M. File C.S. 13263.
[2] A.M. File S. 49531.
[3] It should be noted that 30 lb. bombs were at that time still a requirement, and filling of the cases with incendiary composition was not to affect adversely the former requirement.

included a rounded nose—giving extra room for filling—and a more simple fuze (No. 846). The main body of the Mark II remained, like the Mark I, of solid drawn steel tube, but several methods of fabricating bodies from welded sheet steel were developed at the same time in case of a future shortage of the former.

After satisfactory static trials by C.S.R.D., filled bombs of the new design were tried out by A. and A.E.E. on 23 May 1941.[1] It should be noted here that, these bombs were filled in the method originally proposed for the bomb, that is using *solid* white phosphorus. Of twenty bombs dropped on targets of wood and concrete, all behaved satisfactorily except one, whose failure was traced to a wrongly assembled fuze.

Two alternative schemes for the fitting of the No. 846 fuze were proposed and tried at A. and A.E.E. the following day. In one, the fuze was delivered separately in a water-tight tin ; in the second it was fitted in position in the filling factory. A and A.E.E. recommended the latter method, which was later approved with the concurrence of the Ordnance Board.[2]

Thus the new bomb seemed to offer three advantages over the Mark I :—

(*a*) Easier manufacture.

(*b*) Less handling at the aircraft.

(*c*) Increased filling capacity,

and soon after its trials, D.Arm.D. requested Air Staff approval for the new design. In June, the manufacturer's experimental design was converted to C.S.D.'s D.D.L. series and the bomb approved for use by A.C.A.S.(T). In the same month, future supplies of phosphorus began to be in doubt, and C.S.R.D. was asked to co-operate with Messrs. Albright and Wilson in experiments to reduce the amount used in the bomb ($1\frac{1}{2}$ lb.). Static trials showed little promise, and the use of the full amount continued.

Meanwhile the question of the design of tube had been pursued, and by the end of 1941, the principle of longitudinally welded tube was accepted by D.Arm.D. It was hoped that lease-lend orders for 3,000,000 solid drawn tubes from the U.S.A. might be cancelled, and Messrs. Fisher, Ludlow, Ltd., working to the specifications of the welding advisory service, were commissioned to investigate the best methods of welding.

Some experimental welded bombs were made, and were dropped on the special target at Braid Fell to see if they would give the same penetration as the Mark I (4-inch reinforced concrete) before breaking up. This proved to be so, although the bomb tended to open along the seam and not eject its contents through the tail. This was in a way an advantage, as the amount of phosphorus necessary for complete ignition could be reduced by half a pound. In general, the trial was most satisfactory, the bomb being considered superior to the Mark I and in December 1941, the investigations for the supply of drawn tube from America were suspended and arrangements made for manufacture of welded tube bombs ; to be known as Mark III.[3]

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[1] A. & A.E.E. A.T.O./J.10.

[2] O.B. Proc. 12529 and A.M. File C.S. 13263.

[3] A.M. File C.S. 13263.

Thus by the end of 1941 three types of 30 lb. incendiary bomb were in existence :—

Mark I.—In use until the original order was completed and used (Fuze No. 38).

Mark II.—A simplified pattern (Fuze No. 846).

Mark III.—Similar to Mark II except that the body was welded and contained phosphorus.

So far, little has been said on their incendiary effect, in fact few trials appear to have been done to assess this. However, of interest at this stage is a German circular published in April 1942, which shows that special precautions were necessary to deal with this type of bomb, its penetration of houses was reported as good and its incendiary effect considerable.[1]

A final edition (Mark IV) was yet to appear, and although other forms of incendiary bombs were in service or being developed prior to the advent of this Mark, it is thought worthwhile to complete the account of the 30 lb. series before going on to the others. This bomb was designed to meet—

(*a*) the acute shortage of steel in 1943, and

(*b*) the still more acute shortage of rubber due to Japanese occupation of the chief sources of supply.

The steel shortage was met by reducing the thickness of the bomb body from one-eighth inch to one-tenth inch, and nineteen bombs thus made were dropped at Braid Fell from heights of 6,000 to 70 feet. The results compared very well with the normal bomb, and in the same month a meeting was held at M.A.P. at which representatives of the manufacturers and the Advisory Service on Welding (Ministry of Supply) discussed the change. The internal diameter of the bomb remained the same so no modification of the tail plate was necessary, but some alterations in the welding method were required.

The change in incendiary filling presented many difficulties and called for much research to discover an adequate substitute. (The problem had arisen before the advent of the Mark IV bomb, and indeed a certain number of Mark III models had been charged with a substitute filling.) A substance available in scrap form which proved to be suitable was Perspex ; it was soluble in benzene, and experiments showed that a 5 per cent. solution was satisfactory. Some bombs were filled with the new charge during the latter part of 1942, but because the supply of scrap perspex could not be expected to meet more than a six months' demand, other substitutes were tried, among them cellulose acetate plus cresytic acid dissolved in benzene, and a solution of ethyl cellulose in petrol and benzene. The final choice was the former, and by April 1943, it was the standard filling for 30 lb. bombs. It may be noted that with this mixture it was necessary to isolate the phosphorus from the solution, and in bombs so filled the phosphorus was contained in a separate pocket.[2] By June 1944, operational use of the bomb had indicated that its efficiency as an incendiary weapon was much less than that of the 4 lb. magnesium bomb.

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[1] Foreign Publications Summary, Germany, W/701650/83.

[2] For an interesting series of trials with various fillings, during which bombs were fired from a mortar, *see* Armament Research Department. Report No. 122/43, dated April 1943, by R. F. Phillips and C. O. Thomas.

In that month the merits of the two bombs in area attack was examined by the Incendiary Bombs Test Panel with, as evidence, interpretations of operational results (including that of a raid on Darmstadt when the only incendiaries used were 30 lb.), and information from intelligence sources. The conclusion of the panel was as follows :—[1]

> ' The 30 lb. incendiary bomb was originally introduced to meet an urgent requirement for an incendiary which does not contain magnesium. If 4 lb. incendiaries are now available in sufficient quantity large scale use of the 30 lb. is now no longer imperative. It is considered that in so far as its incendiary effect is concerned, its continued use in area attack is no longer justified. Its use against industrial targets is a separate question which requires detailed analysis of such targets before recommendations can be made.'

This report was reviewed, with other evidence, by the Air Ministry Incendiary Panel, who considered that weight for weight the 30 lb. bomb was four times less efficient than the 4 lb.,[2] and that an additional disadvantage was the large column of smoke it created which tended to obscure the target and hinder following aircraft. With the supply of 4 lb. bombs being adequate, the recommendations of the Panel led to the stopping of manufacture and use of the 30 lb. bomb in the autumn of 1944, by which time just over three million had been used by Bomber Command.[3]

The 4-lb. ' X ' bomb (conclusion)

Meanwhile, in August 1942, a trial was staged by the Road Research Laboratory (M.O.H.S.) to determine the explosive efficiency compared with the German 2 kilo bomb. The method—to test the degree of fragmentation and penetration—was to measure the effect of the fragments against old telephone directories, and showed the German bomb (96 gm. T.N.T.) to be far superior to the British (18 gm. Tetryl).

As a result, C.S.R.D. was urged to accelerate his research into the increase of the H.E. charge, and some experimental bombs containing 38 grammes were tested by the Road Research Laboratory in the same manner on 23 September.[4] Although naturally an improvement on the 18 gramme charge, the results showed fragmentation still to be too coarse and generally inferior (comparative) to the German bomb.

Research and experiment continued and by November 1942 a much more successful bomb with a 38 gramme charge had been developed and tested in dropping trials, and was considered suitable for production. Its introduction was, however, postponed by Air Staff owing to the enormous demand by Bomber Command for the existing Mark I ' X ' bomb, production of which had been planned to be 6 per cent. rising to 10 per cent., of the whole 4 lb. bomb production, but which in fact had at that time only just begun to rise above 1 per cent. Production of the new ' X ' bomb would still further retard that of the old as new machinery was required.

The position was further complicated by a demand from Air Staff for bombs with a longer delay before detonation—up to 10 minutes—which it was found could readily be done with the new type, not with the old, as the explosive

[1] A.M. File C.S. 13263.
[2] Post-war surveys have since proved this opinion wrong.
[3] A.M. File S. 4953.
[4] A.M. File C.S. 11078.

charge in the latter was not insulated.[1] C.S.A.R. was therefore asked to try the effect of increasing the size of the explosive charge container in the Mark I 'X' bomb so that a shellaced cardboard container might be fitted around the H.E. pellet.

It should be noted at this stage, lest confusion should arise over the names of the various types of bomb, that the original type (Mark I 'X') was a modified 4 lb. Mark III bomb. By the end of 1942 production of Mark III's was being modified to become 'X' incendiary bombs which were known as Mark II 'X.' The proposed new bomb with increased explosive charge had not then been adopted, and therefore had no service number. In the end, with the requirements for normal explosive charge but longer delay predominating, production of the 38 gramme charge bomb was dropped. After trials at the Road Research Laboratory and Braid Fell the drilled-out Mark I 'X' bomb was proved satisfactory for longer delay, and it was decided to adopt this type for all future production, to be known as Mark III 'X.'

Meanwhile the Mark I 'X' type continued to be used in all operational incendiary loads, in varying proportions, and there was plenty of evidence from German sources that the explosive incendiary bomb had created a very difficult problem in fire-fighting; among other things the German people were warned to treat every incendiary bomb as if it contained an explosive charge.[2] From numerous enemy A.R.P. reports and the like it was clear that increased delays would be of advantage to our incendiary bombing effort, and in April 1943 the Air Staff became increasingly anxious to have these as soon as possible. By July C.S.A.R. had produced a delay composition theoretically meeting this requirement, but unfortunately the pressing of it into pellets created manufacturing difficulties.[3] However, some experimental bombs were made up and dropped at Braid Fell in the following October, with very poor results.[4] Of 142 explosions recorded these were the approximate delays: 30 seconds to 3 minutes, 7·1 per cent.; 3 to 6 minutes, 71·1 per cent.; 6 to 10 minutes, 5·6 per cent.; the remainder between 10 and 14 minutes.

It did not seem as though these figures could be improved upon, as it was found that the position of the bomb at rest considerably affected the length of delay,[5] and D.Arm.D. recommended that all 'X' type bombs should have this new composition, which, at any rate, was better than anything before, and would at least give a percentage of surprise long delays. To this D.O.R. agreed, provided it did not interfere with output, and C.S.A.R. was requested to do further research into the delay problem.

Experiments to produce a more reliable long delay were difficult and protracted, and it was to be November 1944 before a reasonably successful composition was evolved containing sucrose instead of lactose.[6] From the final trials it was calculated that the majority of bombs would detonate between 4 and 8 minutes, and about 10 per cent. between 8 and 14 minutes, and by the end of 1944, complete change-over to this composition was made.

[1] M.A.P. File S.B. 13337.
[2] A.M. File C.S. 11078.
[3] 35 per cent. unwaxed lactose. 65 per cent. Barium Nitrate.
[4] A.M. File C.S. 11078.
[5] *e.g.*, Whether the molten magnesium flowed away from, or towards, the H.E. pellet. For a detailed report on the problem *see* C.S.A.R./T.P./4121, 30 October 1943. A.M. File C.S. 11078.
[6] M.A.P. File S.B. 13337/7.

The 4 lb. bomb may be considered as one of the most successful incendiaries produced. Its design and production went forward with little delay, and the only major modification was imposed by economic or tactical necessity. It remained the standard incendiary bomb throughout the war. That there were failures on operations cannot be denied though reports of these may have been exaggerated, but such failures were due mostly to the very simplicity of the bomb design. Its ballistic-shape was not such as would ensure stability at low heights, and during the later stages of the war, when ' cluster ' release became predominant, interference between bombs during the initial part of the fall may have accounted for failures of the bomb to reach the target in the best attitude of impact. On the other hand, simplicity of design made it possible for the bomb to be produced in the vast quantities required by the Air Staff, and this reason alone justifies the acceptance of a small percentage of failures.

The production and expenditure of 4 lb. incendiary bombs may be measured from the following table which shows the total dropped by Bomber Command during the war :—

Year.	*From S.B.C.s.*	*In Various Clusters.*
1940	508,993	
1941	2,082,669	
1942	8,010,926	
1943	27,371,900 (including 1,469,853 ' X,' 3,750 ' E ')	7,127,286
1944	19,890,800 (including 1,498,723 ' X ')	
1945	7,452,067 (including 690,423 ' X ')	7,204,414

This huge total of nearly 80 million bombs was probably some 80 per cent. of the number produced.

The 30 lb. ' J ' bomb

In the preceding account of the 30 lb. liquid filled bomb, mention was made of how the shortage of rubber from 1942 onwards caused production difficulties and much research into alternative fillings for that bomb, in itself a temporary substitute for a percentage of 4 lb. bombs, due to a shortage of magnesium and steel.

In June 1942, Air Staff published a memorandum dealing with the problem of raw materials for incendiary bombs and stating the requirements for a bomb which would, in manufacture, be largely independent of the materials in short supply. In brief, they required an alternative of some viscous liquid filling, to function by some ejection principle, to be strong enough to be operative after release up to 15,000 feet and penetration of the roof and top floor of a typical German dwelling house. Carriage in aircraft was to permit the greatest possible number of bombs—preferably in clusters—and size and weight to be as small as possible, consistent with a high charge/weight ratio. The usual conditions for simple fuzing, safety, and ease of manufacture, were stipulated.[1] These requirements, borne of economic necessity, were to lead to the eventual production of the ' J ' (jet) type incendiary bombs.

The ' J ' (jet) type incendiary bomb had its origin in the autumn of 1942 in the laboratories of Leeds University, where the Ministry of Home Security had established a research station under Professor D. T. A. Townend. During investigation of problems concerned with defence against incendiary bombs, it

[1] A.M. File C.S. 15591.

was discovered that what appeared to be an extremely efficient incendiary agent could be constructed by burning a liquid hydrocarbon at the end of an oscillating jet which could sweep inflammable surfaces within its range. In the early experiments the hydro-carbon Butane was used, contained in a cylinder under pressure. It was evident that although this procedure was simple enough on the ground, it was another matter to produce a bomb which might be carried safety in an aircraft and released, probably from a great height, so that it would have to be robust enough to withstand impact with the ground, after which it must automatically turn on its jet and ignite the issuing liquid.

The idea was considered in the autumn of 1942 by C.S.R.D., who decided that it was too complicated and declined to undertake its development. The Ministry of Home Security was, however, more optimistic, being convinced that the idea had practical possibilities, and continued to sponsor research.

In October 1942 it was decided that the jet flame bomb had advanced 'from the demonstration of a principle to the designing of a bomb to fit particular stowages and to meet Air Staff requirements,' and that therefore future development should be taken over by the incendiary bomb branch of D.Arm.D.[1] It was arranged that continued help should be given by the Ministry of Home Security scientists at Leeds. The bomb designed and produced was a cylindrical steel casing containing a solution of methane in petrol, under pressure. On impact a thermite charge in the central tube was ignited, heating the petrol methane mixture. At the correct temperature a metal disc of low melting point was fused, and the mixture issued through a flexible tube in the form of a flaming jet some 15 feet in length. The bomb weighed 30 lb. and contained 1·3 gallons of methane-petrol.

Between January and March 1943 static firing trials to determine its incendiary and penetrative effect against representative German dwellings and the best method of igniting the petrol streams, best size of jet and so forth, indicated that with simplification the bomb might become the most efficient incendiary weapon yet designed.[2] No air trials had so far been done, and before these were carried out the bomb was tested to discover the effect of small arms fire on aircraft. This test at Orfordness in February 1943 showed that the bomb was safe when struck by A.P. ammunition but was ignited by A.P. incendiary. Even then, though a jet of flame appeared, it lasted for five seconds only and did no structural damage to the aircraft.

At this stage of development (March 1943) it was estimated that given high priority and an absence of serious complications, manufacture could commence within six months. A demonstration was staged when comparative trials of the 4 lb., the normal 30 lb. and the new 'J' bomb, were made in some condemned houses in Hammersmith. In this the jet bomb was oustanding. The 4 lb. incendiary in unfavourable positions did nothing, and in favourable positions only started a slow growing fire. The 30 lb. bomb behaved similarly, but the 'J' bomb raised a fire that was beyond the control of 'fire-watchers' in less than one minute.

Members of the Air Staff and Ordnance Board who witnessed the demonstration were greatly impressed, A.C.A.S.(T.R.) immediately informing the Controller of Research and Development (M.A.P.) that he wished development and production to go ahead on the highest priority. A.C.A.S. (Ops.) was of the opinion

[1] M.A.P. File S.B. 43268/2.
[2] A.M. File C.S. 15591/1.

that if it could be made operationally practicable it would—if incendiarism was to be the main weapon of bomber attack—eliminate the whole of the fire-watching organisation in Germany, seriously disorganise the second line of fire defence (fire brigades), and virtually double or treble the effect of the bomber force.

The Ordnance Board in summing up the trials was equally impressed as the following extract from their report will confirm :—

> 'The Board are sufficiently impressed with the performance of the 'J' bomb to recommend that once the supply position for these bombs is clear there is no cogent technical reason for continuing the production of any other type of incendiary bomb.'[1]

This high promise was unfortunately not to be fulfilled ; the question of the bomb being made operationally practicable should here be borne in mind, but as far as this outstanding trial is concerned the result was a revision of Air Staff requirements to fit in with current development, and an order for production at the earliest possible date of 25,000 per week rising to 250,000.[2] It was recognised that with such a design, failures would be inevitable, but the Air Staff was prepared to accept 50 per cent. of such to be begin with. Meanwhile two more points in development had been made clear ; the bomb was to be in clusters, and it would need a parachute, to function when the cluster broke, to reduce the bomb T.V. to about 180 feet per second in order to give optimum penetration of buildings.[3]

The first air trials took place on 26 March 1943 when sixteen bombs were released singly from 2,000 feet on to concrete. This trial was only moderately successful, failures occurring with parachutes, ignition systems and bombs breaking up, but at that stage of development was considered satisfactory, as work on the parachute was still going on and the target was not representative of German buildings. Development went ahead on the cluster, parachute, and ignition system, and by the end of April when Bomber Command were becoming interested in the progress, it was reported that designs were clear for production, except those of the cluster and parachute, and that an order for 1,000,000 bombs had been placed.

In the following August it was hoped to carry out final acceptance trials against a small village called Shingle Street, near Orfordness, but this project was abandoned as the buildings—mainly small bungalows—were not representative of German targets, so more dropping trials of clusters had to be done at Porton, which, although proving the operation of clusters and parachute to be satisfactory, gave no indication of the incendiary effect of the bombs from the air.

By the end of August I.C.I. Ltd. estimated their production of filled bombs to be 1,000 per week, rising, but cluster production was likely to be behind that of the bombs for some time. Despite the early promises and hopes for large production, however, innumerable difficulties began to crop up to hinder any large scale manufacture. These in the main concerned the flexible tube and size of jet, the thermite in the central tube, and the methane-petrol mixture.

Towards the end of the year doubts began to arise as to whether the bomb was going to be an operational success, even if the various production problems could be solved. Penetration trials of inert bombs against some houses at Leysdown,

[1] O.B. Proc. Q. 1093.
[2] M.A.P. File S.B. 42368/3.
[3] M.A.P. File S.B. 42368/2.

Isle of Sheppey, had been disappointing; a number of bombs being deflected on impact; clusters had poor ballistics and the bomb spread was too close; and, from stowage trials done in Lancaster aircraft, Bomber Command considered the clusters uneconomical compared with the existing bomb load.[1]

In December 1943 the Director of Armament Requirements, writing to A.C.A.S.(T.R.), said he was unhappy about the 'J' bomb position. The only way to test the bomb was in a series of operational attacks, using, say, at least 40,000 bombs per raid, before any valuable comparison with the 4 lb. and 30 lb. incendiary bombs could be made. Bomber Command had suggested a minimum of 25,000 bombs for such an operational trial and with the total available being only 20,000 by the end of the year, Air Ministry asked the Command to assist development by doing high altitude trials on one of its ranges: the usual bomb testing ranges being seriously overloaded with trials. Although a large programme was planned and agreed upon, bad weather and operational commitments caused these trials to be only 'nibbled' at, a few clusters being dropped at Wainfleet and Rushford ranges early in January 1944 with inconclusive results.

So came February 1944, and the position that the 'J' bomb was still far from past its 'teething troubles'; development was still incomplete for reasons of manufacture and outstanding trials, and there were not sufficient approved bombs for an operational trial. In that month I.C.I. Ltd. pointed out that up till then 50,000 filled bombs had been produced of which only 6,000 were acceptable for operational trials. The remainder were suspected as being unsuitable for the following reasons :—

(*a*) Parachute cords under suspicion	13,000
(*b*) Central tubes filled with unreliable composition ..	21,000
(*c*) Reasons (*a*) and (*b*)	5,000
(*d*) Waiting re-inspection	5,000
	44,000

A great number of these bombs were unsuitable as a result of trials held subsequent to manufacture, which were few and far between, with the result that manufacture went on and stocks of useless bombs accumulated. The firm could only do static trials which could not cover other possible causes of failure which were :—

(*a*) Failure of barometric fuze.

(*b*) Failure of cluster to open.

(*c*) Failure of parachutes.

(*d*) Failure of bomb strike.

and it was pointed out that only comprehensive high altitude trials could really clear up the matter. Finally it was suggested that if sufficient importance was still attached to the large scale production of 'J' bombs, one or two aircraft and pilots for whole time tests was not too big a price to pay, to achieve that.

This summary of the situation, representing as it did, the manufacturers' point of view, was investigated by Air Staff and the Ministry of Aircraft Production, who, although agreeing in the main, did not agree that delay in completing development was chiefly due to the shortage of air trials. While it was

[1] A.M. File C.S. 15591/1.

true that there was a serious shortage of aircraft available for these trials, and there was only one testing range really suitable for this type of clustered incendiary, most of the troubles hampering development had occurred before air trials were due, and were caused by bad manufacture, bad assembly and faulty inspection.

Although a further supply of bombs was allocated for high level trials at Wainfleet, no more had been dropped by May 1944 when, with some of the production difficulties having been overcome, enough improved bombs were ready for the first operational trial.

It had been the intention to use them, if possible on a virgin target, in order to get the best idea of their effectiveness.[1] This however was not practicable for various reasons, and the target attacked was Brunswick on the night of 22/23 April, when the whole incendiary load—some 432 tons—was of 30 lb. 'J' bombs. This long awaited operation was almost useless as a comparative test, for almost all of the bombs fell in the open-spaced south-east outskirts of the town, thus providing no real opportunity for a large conflagration. What analysis and assessment was possible did however tend to indicate that weight for weight the 'J' bomb was very inferior to the 4 lb. bomb.

In the absence of any conclusive evidence as to merit of the bomb a further order for 1,000,000 was placed in July, it being the intention to review this order after further operational use. From then until October 'J' bombs were used as part incendiary load in attacks on Kiel on 23 July, Stuttgart on 24, 25 and 28 July, Stettin on 16 August and Konigsberg on 29 August; again with inconclusive results. All the targets had been previously attacked, though Stettin and Konigsberg were more or less virgin targets from the point of view of incendiary attack. However, the loads carried were mixed and the method of attacking half of each town with 'J' bombs and the other half with ordinary incendiary bombs, did not prevent a certain amount of overlapping. Thus the earlier hopes that several operations might establish the efficiency of 'J' bombs or otherwise were unfulfilled.[2]

Certainly the bomb had fallen into disrepute in Bomber Command, for on 6 October the C.-in-C. reported to Air Ministry that, according to the Operational Research Section of the Command, an investigation of the results of 'J' bomb raids to date showed the 4 lb. clustered bombs to be twice as effective as the jet bomb. He regarded as deplorable the fact that so much time, energy, and misguided enthusiasm had been spent on such an unpromising weapon, to the detriment of the clustered 4 lb. incendiary, and recommended that production of the jet bomb should cease.

To this Air Ministry did not agree, pointing our that the Incendiary Panel—on which Bomber Command were represented—had fully examined the results of the raids, as well as the O.R.S. report, and they were of the opinion that the full potentialities of the 'J' bomb might well not have been assessed. Therefore before condemning the weapon, Bomber Command were invited to use it again, with once more the suggestion that it be used against targets that had not been heavily attacked before.

To return to development progress for a moment, the bomb had by then certainly been much simplified. Between April 1944 and October the whole trend of development had been to simplify the construction of this vastly

[1] A.M. File C.S. 15591.

[2] A.M. File C.S. 15591/2.

over-complicated bomb ; in particular the ejection valve, parachute box, and firing had been improved.[1] However, with another type of 'J' bomb (20 lb.) on the way, production of the existing bomb was cut down from 40,000 to 30,000 per week, and all further development ceased by the end of October.

By the end of November, the question of the usefulness of the bombs had again been reviewed, following their use in mixed loads against Kaiserlauten on 27 September and Nuremberg on 19 October, and it was the opinion of the Air Staff that there was still insufficient evidence to justify the C.-in-C. Bomber Command's recommendation. The latter, however, was in no uncertain mind as to the value of the 'J' bomb. In the raid on Kaiserlauten only 420 were used, and, according to a prisoner of war who had been engaged in salvage work after the raid, a great number of these had failed ; either the cluster had not opened, or individual bombs were found intact. Whilst this interrogation report was being studied for technical information, the C.-in-C. obtained ' fortuitously ' as he put it, a report of what the prisoner had alleged. In 1944, Bomber Command had put in terrific efforts against oil targets, with very considerable success, and when the C.-in-C. heard that the Germans were picking up all our dud 'J' bombs, knocking a hole in them and tipping the contents into the petrol tanks of their M.T. vehicles, the atmosphere in his office got somewhat tense.

He then wrote to the Air Ministry an indictment of the 'J' bomb, which he described as an expensive failure, and vastly less effective than the clustered 4 lb. magnesium incendiary. His chief complaint was that although he had continuously asked for increased supplies of cluster containers for 4 lb. bombs in vain, because, it was alleged, materials and labour were inadequate, such containers had been produced readily for 'J' bombs.[2] Development had, in fact, occupied the experts for over eighteen months, and when further work ceased, in April 1944, the bomb was still far from being technically sound.[3] The lack of suitable operational trials did not, in the opinion of Air Staff, give M.A.P. or the Incendiary Panel sufficient evidence to evaluate the effectiveness of the bomb, and no satisfactory assessment of the bomb ever was, or has been made.[4] A total of 413,165 was dropped in the raids previously referred to, and this was the total operational use of the bomb. Arrangements were made with the U.S.A. Air Force to use them in Europe early in 1945, but did not materialise. Production on a reduced scale continued though, and work in the latter part of 1944 and the first half of 1945 was directed to making the bomb suitable for stowage and use in the Far East, but again no bombs were used.

The 20 lb. ' J ' bomb

Even had the 30 lb. bomb proved an outstanding success as a fire-raiser, it had one serious disadvantage which would always have reduced its value, the liquid filling gave constant difficulty. Special machines had been devised to fill the bombs, but these were still complicated and extravagant, somewhat dangerous, and trouble with leakage in storage was always present. This difficulty, together with a great deal of the simplification of component parts, seemed to have been surmounted in a rival bomb of similar design which originated in the War Office (D.M.D.) in 1943.

[1] M.A.P. File S.B. 42368/21.
[2] A.M. File C.S. 15591/2.
[3] M.A.P. File S.B. 42368.
[4] A.M. File C.S. 15591/2.

This was a jet-bomb originally weighing 10 lb. but in its final design about 23 lb.; having a solid naphthalene filling cast round a heater element which, on burning, vaporised the naphthalene and forced it from the bomb in the form of a jet. Early models were found to be unstable, but in later types a cylindrical metal tail (spring loaded) was fitted which collapsed over the bomb body during carriage in a cluster, but on release sprang out.

The solid filling had many advantages over the liquid. It gave the bomb extra strength to withstand impact, and in penetration tests, fired from a mortar, the smaller bomb proved superior to the 30 lb. 'J' against concrete and typical German domestic buildings.[1] As a fire-raiser it promised to be at least equal to the larger bomb, and both M.A.P. and the Air Staff were impressed by its performance against derelict houses at Hammersmith. The bomb then required no parachute, another point greatly in its favour, and 9,000 were ordered for development trials.

With the approach of the end of the war in Europe, more and more thought was naturally given to weapons for the attack of Japanese structures and it was considered that the 20 lb. bomb would be the more suitable in size.[2] This advantage, added to ease of manufacture, filling, and reduced cost, led to the development of the bomb as the jet incendiary for war in the Far East.

Difficulties in obtaining a suitable cordite to heat the main filling prevented any early large production of the bomb. Whilst this delay was going on, the need for a parachute arose because the T.V. of the bomb was too high for that required against Japanese targets. The time taken up in finding a suitable cordite was therefore utilised for the design of a parachute; an unfortunate necessity, for parachute bombs have always been difficult to design, fit and use. However, by March 1945 the parachute type had been successfully tried and in July the 30 lb. 'J' bomb ceased to be a requirement.[3] The smaller bomb only was contemplated for use in the Far East, but the sudden ending of the war prevented its use.

The foregoing account concludes the history of the small to medium incendiary bombs and in fact covers the main types used during 1939–1945. Other large incendiary bombs were developed and used in minor quantities, as were one or two special weapons for use against forests, and these will now be briefly discussed.

Large incendiary bombs

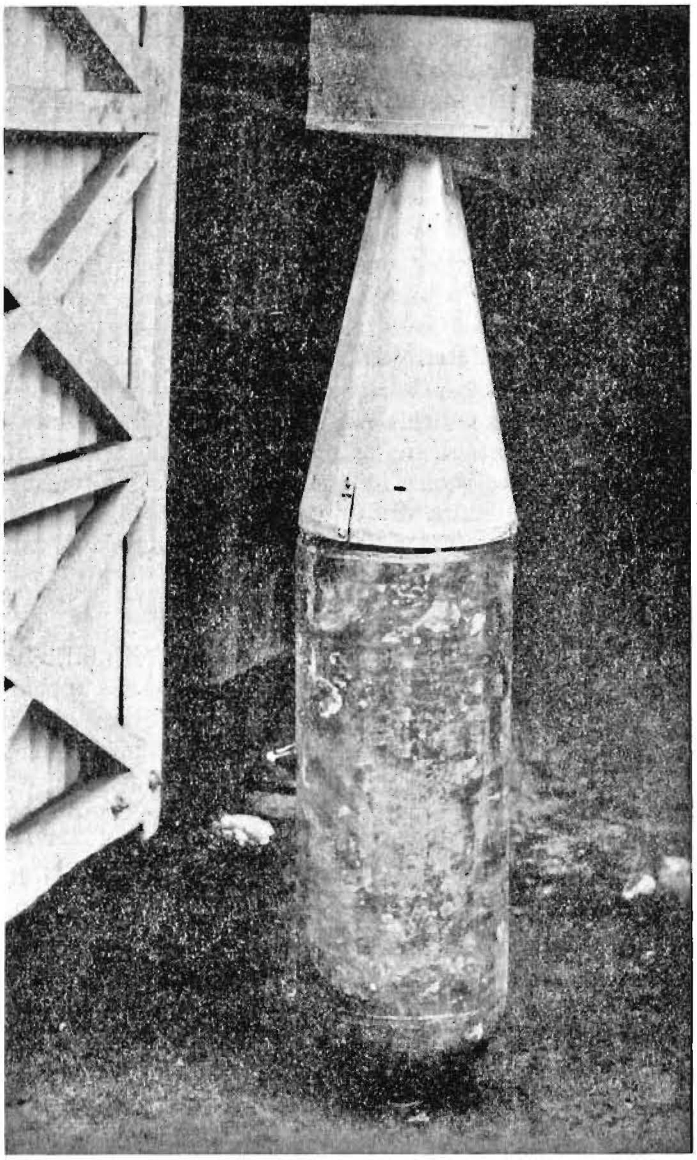
Of these there were three sizes, 250 lb., 400 lb., and 2,700 lb., all of which can be briefly dealt with, as for various circumstances they were rarely used.

250 lb. bomb.

This was the standard L.C. bomb case filled with a mixture of paraffin and rags, using an instantaneous fuze and ejection charge. Introduced in 1940 for use against forests it was little used as such and was not very successful.[4] In 1941 it was considered for the attack of such targets as industrial works, docks, and warehouses, and trials with a rubber/benzole filling were successful. In practice however it was never more than a 'make-weight' bomb, its size in any case being unsuitable, for by mid 1941 the superiority of large numbers

[1] M.A.P. File S.B. 42368.
[2] O.B. Proc. Q. 2719.
[3] O.B. Proc. Q. 3586.
[4] A.M. File S. 6909.

of small bombs was all too evident. Production too was always likely to be limited by chemical warfare requirements. In all some 18,000 were thus converted, of which Bomber Command used about 7,000, the remainder being re-converted to target indicator bombs after ceasing to be an incendiary requirement in July 1942.



250 lb. Mark 1 Incendiary Bomb

400 lb. petrol/gel. bomb.

This was specially designed and developed in 1944 for the attack of small craft in harbours in the Far East. It was a drum-type bomb in two portions, the front and main part being filled with petrol, a smaller rear portion contained a cellulose/acetate mixture and was ignited by a detonator and burster charge. Development trials in this country were successful and 500 bombs were sent to South East Asia Command in December 1944[1] for operational trials, but it is not known whether these were ever held. The abrupt ending of the war in that theatre stopped any production for operational use.

2,700 lb. bomb.

This was sometimes termed a 'four thousand pounder' because it was a standard 4,000 lb. H.C. bomb case adapted for incendiary filling and as such it was approximately the weight quoted. A few were used by Bomber Command in 1942 and 1943 as marker bombs but were not suitable and the idea was dropped. Early in 1944, the bomb was re-developed as a low attack incendiary weapon against fortified enemy positions in Europe.[2] This time a filling of perspex/gel. and liquid phosphorous was used. Progress with the bomb did not go beyond the development trial stage and by July 1944, it was no longer required for operational use.

Special weapons for creating forest fires

Many types of incendiary bomb have from time to time been tested to find the most effective weapon for this particular attack. A study of various reports on these experiments seems to suggest that the problem of attacking forests is not so much the choice of weapon as the right forest conditions. Given these; for example thick dry undergrowth, low humidity, light wind, almost any type of non-penetrative incendiary will start a fire, but no bomb will ignite a forest which is green and wet.

50 lb. bomb.

In July 1941, some trials were held in a wood near Burford, Surrey, under almost ideal conditions. All the incendiary bombs in service at that time were tested, as well as a specially made up 65 lb. L.C. bomb case filled with rubber-benzole-phosphorus. This latter was simply a square tin originally intended for chemical warfare, the phosphorus content giving self ignition when the tin burst on impact. Filled with incendiary composition the bomb weighed 50 lb., by which name it came to be known.

In the trials this type gave the most promising results and 10,000 were ordered and were ready by the middle of August; it being intended to use them in that month or September.[3] For various reasons the plan was never put into operation, but about half the quantity were used by Bomber Command later in that year as part load in area attacks. The forest fire plans were dropped in the autumn of 1941 and the bomb withdrawn from service.

'Razzle' and 'Decker'

These were code names for celluloid strips joined together with a phosphorus pellet in between them. The idea was first developed in 1940 for attacks against crops, in particular corn, the intention being to store them in tins of five hundred in water and alcohol and to drop them by pouring out of the tin down the flare chute.

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[1] A.M. File C.S. 22295.
[2] A.M. File C.S. 23225.
[3] A.M. File S. 4941.

The first type known as ' Razzle ' was rushed into production in the summer of 1940, various static and air trials having established that they would ignite satisfactorily, but whether they would ignite crops remained to be seen. In this matter they were soon proved to be useless, tests in a field of dry ready-to-cut corn in August of that year being a failure. Conditions were as near perfect as would ever be obtained in Europe, even with paraffin sprayed on the corn, the pellets failed to ignite it. After many attempts the only conclusion that could be reached was that even under the most favourable conditions it was almost impossible to damage standing crops in Europe by incendiarism.

The project was therefore abandoned, but in the autumn of 1940 large numbers were dropped over Germany to create a general nuisance.[1] No very convincing reports of extensive damage either to crops or forests were received, and there was little evidence that the Germans took any special precautions to deal with them, beyond warning the populace of their delayed incendiary effect.

' Decker '[2] was designed as an alternative form of incendiary leaf for possible use against forests and was really a ' sandwich ' of celluloid and rubber strips with a phosphorus pellet, and might at least have provided a means of using up some of the millions of ' Razzle ' units left on hand. Like the original, however, ' Decker ' was never used in a special operation against forests ; some were used for nuisance values and the whole idea was dropped in 1941.[3]

Conclusion

The following is a summary of the effectiveness of incendiary bombs generally and where possible by type and size, based on the findings of the Weapons Effectiveness Panel of the British Bombing Survey Unit.[4]

(*a*) *Industrial buildings.*

It is shown that incendiary bombs were considerably more effective than high explosives against light engineering targets and that there was no marked difference between the efficiency of the 4 lb. and 30 lb. Mark IV, the bombs in major use. There is evidence that incendiaries generally were not as effective as medium H.E. bombs against iron and steel works, oil refineries, and synthetic oil plants.

The 30 lb. ' J ' bomb is not assessed as it was so little used.

(*b*) *4 lb. bombs against housing.*

This assessment is based on data from surveys of three German towns in which the effects of incendiaries had not been obliterated by simultaneous or subsequent attacks with high explosives, and presents a clear case for the superiority of this type of bomb against area targets.

The probability of a 4 lb. bomb causing serious fire damage to a domestic building is shown to be in the order of 20 per cent. Of 560 bombs located by the survey team in two towns the probability of penetration and ignition was about 99 per cent. The positions at which these bombs came to rest when dropped in clusters were 31·9 per cent. above top floor ; 52·3 per cent. on top floor and 15·8 per cent. below top floor. If dropped from small bomb containers the corresponding figures would be 24·6 per cent., 39·3 per cent., and 36·1 per cent. respectively.

[1] A.M. File S. 48336 and O.B. Proc. Q. 31/40.
[2] A.M. File S. 48336.
[3] M.A.P. File S.B. 6102.
[4] D.G. Arm. W.E./S. 3507.

(*c*) *Damage to machine tools.*

No data were available to present a firm estimate of incendiary values against machine tools, but a study of the results of H.E./Incendiary attacks on nine German factories suggests there was no marked difference in effectiveness per ton of the two kinds of bomb.

U.S.A. strategic bombing survey

A large series of reports similar to those quoted above have been prepared by the United States.[1] A few extracts from those concerning R.A.F. incendiary attacks may be of interest.

(*a*) *Damage to cities.*

The cities of Hamburg, Kassel, Darmstadt and Wuppertal were surveyed and it was estimated that 70–80 per cent. of the damage was caused by fire.

Research by the Ministry of Home Security on thirty-five raids on fifteen cities shows that incendiaries caused approximately five times more damage (ton for ton) than H.E. A high density of incendiary bombs can cause almost 100 per cent. destruction.

The use of phosphorus in the 30 lb. bomb was most effective ; not only were fire guards afraid of phosphorus but smoke obscured the bomb and made it difficult to extinguish.

(*b*) *The effectiveness of mixed H.E./Incendiary attacks.*

It was emphasised that the maximum effect of incendiarism was best produced by mixture of H.E./Incendiary bombs because of the deterrent effect of H.E. on firefighters and the disruptional effect on fire-fighting services, *e.g.*, water mains. No conclusive data are available to estimate firmly the ideal proportions in mixed loads, but it was suggested that 50/50 was probably best. Above that figure for incendiaries tended to show that the effectiveness of the attack diminished.

(*c*) *Comparative values of 4 lb. and 30 lb. bombs.*

As with the British surveys, these two types of bomb only are reported on in detail. The general opinion, based on field surveys and interrogation of fire-chiefs and other officials in German cities, was that the two bombs were ton for ton about equal in effect. Each bomb had advantages and disadvantages peculiar to its type, the four pounder being superior in numbers carried, but was more easily extinguished or removed, whilst the thirty pounder had greater fire-raising qualities, was harder to extinguish, but, of course, was less in numbers per ton. In addition, it had greater penetrative power than the 4 lb. bomb.

(*d*) *4 lb. Incendiary (X) bombs.*

It appears these had a certain nuisance value, but were of little effect in deterring fire-guards, who, although instructed to wait at least five minutes before tackling 4 lb. bombs, usually ignored those instructions. It was the high explosive bombs dropped with incendiaries that prevented fire-fighters from promptly combating fires.

[1] U.S. Strategic Bombing Survey. Physical Damage Division Report No. 61, October 1945.

CHAPTER 7

LIGHT CASE (CHEMICAL FILLED) BOMBS

Legality of gas weapons

The following extract is taken from the confidential supplement to Air Power and War Rights by J. M. Spaight :—

Policy with regard to the possible use of Gas as a Retaliatory Measure in War

C.I.D. (Committee of Imperial Defence)—Extract from memorandum by Chief of Staff Sub-Committee, June 1936 :—[1]

> 'Recent events, in our opinion, make it impossible to be sure that gas will not be used against us in war, indeed, the probabilities are in the other direction. We therefore consider that steps should be taken to provide stocks of the latest and most potent forms of gas, so that, if necessary, we may be able effectively to retaliate without a day's delay. To produce these stocks and to form a nucleus for production on a war scale, a factory will have to be set up and possibly some enlargement of existing experimental establishments will be required.'

Extract from memorandum prepared by the War Office and the Air Ministry, submitted to C.I.D. on 26 July 1938 :—[2]

The Manufacture of Toxic Gas for use in War

Para. 30. Conclusions.

'(i) There is no doubt that Germany is making very thorough arrangements for the provision of gas and its employment in the war. She is well ahead of this country and consequently it is necessary that measures should be initiated at once to enable us to retaliate should gas be used against us in war.

(ii) Gas is not alternative to, but complementary to, the high explosive bomb, and if used in conjunction with them will hasten the work of dislocating and disorganising the national life and demoralising the community.

(iii) The employment of gas, as well as high explosive and incendiary bombs, would augment the effectiveness of an air offensive to a degree unattainable by other means.

(vi) Kernet factory should be developed to give an output of 300 tons a month.

(ix) The knowledge that we possess gas for retaliation will have a reassuring effect at home and be a strong deterrent to its employment by potential enemies abroad.'

The use of poison gas in war[3]

A letter dated 12 November 1938 from the Foreign Office to the C.I.D. suggested that an attempt be made, on the outbreak of war, to obtain from the enemy government, even though a signatory of the Geneva Gas Protocol of

[1] C.I.D. 1237B.
[2] C.I.D. 1465B.
[3] C.I.D. 1489B.

1925, an assurance that they will abide by the terms of that instrument. The undertaking would be of considerable propaganda value if the enemy did violate the Gas Protocol later. (An assurance was asked for by our Minister in Berlin when requesting his passports on 3 September 1939, and was given by the German Government.)

White phosphorus

The question of the use of white phosphorus arose in 1943, and again in 1944. It is primarily a smoke producing chemical, but its property of igniting spontaneously and burning vigorously when exposed to the air, make it one of the finest materials produced for incendiary purposes. (The Germans usually referred to our 4 lb. incendiary bombs as 'Phosphorus Canisters.') In contact with the human body it produces burns which are slow and difficult to heal. It was considered by the Foreign Office to come within the prohibition contained in the Geneva Gas Protocol, and the Chiefs of Staff agreed that it should not be used as a casuality producing agent against troops in the open. The Chiefs of Staff considered, however, that there was no objection to its use as a thermal incendiary weapon, and in October 1944 agreed to a proposal by the Second Tactical Air Force that rocket projectiles with heads filled with white, liquid phosphorus, or thickening fuel, could be used to dislodge the enemy from strongpoints too heavily defended by 'flak' to permit low level bombing and too strong to be destroyed by the 60 lb. rocket projectile.[1]

Early history

After the first world war the British Government, having had some experience of the ease with which signed agreements are broken during hostilities, added a rider to the Gas Protocol of 1925 which, whilst re-affirming their intention to regard chemical warfare as illegal, reserved the right to adopt this form of warfare should it be used by any other power. It should be noted that by these agreements, only the use of gas weapons was outlawed and not their production and development. On this ruling it was decided that development of such weapons and investigations into methods of protection from their use, was essential to a state of preparedness of the nation.

This chapter briefly summarises the effort made in that direction by the British Government between the two world wars, and to avoid confusion, each missile is dealt with as a separate item and not in the chronological order of their development. For this reason the reader is asked to bear in mind that, in common with the majority of weapons, improvements and consequent alterations in design, are often dependent upon the trials and tests carried out over the whole range of similar weapons.

Early in the post 1914/18 war period it was realised that a convenient means of attack with, and retaliation to 'chemical' operations, was available in the carriage by aircraft of a chemically filled missile. For this, and economic reasons, initial development was confined to the adaption of existing stocks of high explosive bomb bodies, which, although not by any means ideal for the purpose, offered a means of justifying expenditure on the design and development of the thin-cased bomb having the high charge/weight ratio necessary for this type of warfare.

[1] C.O.S. (44) 339th Meeting.

Attempts to convert the available bomb bodies into chemical containers failed for many reasons, not the least of which was the seemingly impossible task of sealing completely the many body joints. In 1925, the Air Staff decided therefore to cancel the conversion work and authorise the design of a special light-cased gas bomb weighing approximately 50 lb.[1]

The 50 lb. L.C. bomb

The first two 50 lb. L.C. bombs, differing in wall thickness, successfully completed their internal pressure, rough usage and functional tests at the experimental station at Porton in November 1925, and early in February of the next year, a further bomb with an even thinner case (0·08 inches) was ordered.[2] Twelve bombs of this type were ready for trials in November 1926 and four months later had successfully passed all initial tests.

Progress up to this stage had been slow but increasingly successful and the remainder of 1927 was occupied with testing a variety of sizes of burster charges and exploders. The experimental station at Porton, where the majority of the trials and tests took place, had, in a report on the 50 lb. bomb, suggested that although successful in the tests, it was wasteful in filling and distribution, and that this might be avoided, without detriment to casualty effectiveness, by a smaller bomb of similar design weighing about 20 lb.[3]

The Air Staff decided to follow the Porton recommendation and requested that the designs of the 50 lb. L.C. be completed for approval and sealing. To this latter action Porton was not in agreement, since up to that time, all trials and conclusions were based on bombs charged with the mustard gas substitute, and many further trials with the operational filling were desirable before the design was finally in a fit state for approval. Accordingly approval and sealing was postponed and in November 1927 a further twenty experimental 50 lb. bombs were ordered.

Their trials, involving filling methods, gasproof sealing and live dropping, were carried out at intervals during 1928, and in February of the next year the design and specification was approved pending storage trials. It was not until March 1933 that the storage or 'keeping' trials, after many internal modifications to the bomb, proved finally successful and the much amended specification was given its final Air Staff approval.

The 50 lb. L.C. bomb, having taken some eight years to develop was never advanced beyond that stage, for when full scale production was requested in June 1936, aircraft design, speeds and carrying capacity, had so changed that the Air Staff had decided to replace it with a larger bomb later to be known as the 250 lb. L.C.[4]

The 20 lb. L.C. bomb

The 20 lb. L.C. bomb proposed by Porton, was designed for a filling of liquid mustard (H.S.) and was evolved to take the place of the 50 lb. type and overcome the faults discovered in its trials. Principal among these was poor distribution of the liquid gas, particularly over soft targets, and to rectify this it was decided to incorporate a method of ejection of the filling by means of a small charge and fuze.

[1] A.M. File S. 22603.

[2] Assessment of bomb value was obtained by measuring the splash area from a filling of Methyl Salicylate in substitution for fluid Mustard gas.

[3] A.M. File S. 26222.

[4] A.M. File S. 25511/2.

The proposed bomb, streamlined in form, was to be carried in 'Small Bomb Containers' and employed against troops in the open, docks, aerodromes and other open and thinly protected targets. The Deputy Chief of Air Staff (D.C.A.S.) approved the recommendations and in April 1936 the Chief Superintendent of the Chemical Defence Research Department was authorised to proceed.[1]

Difficulties arose once again with conversion and finances, and because of the high priority which the project was allotted, the Assistant Director of Armament Research and Development decided to reduce costs and speed manufacture by using an unstreamlined cylindrical shape. The adoption of this shape and consequent increase in filling content, increased the overall weight to approximately 30 lb. and involved deletion of the 20 lb. bomb on which all further development ceased.

The 30 lb. L.C. bomb

Before development had really commenced, the Air Staff increased the performance requirement to include efficiency of contamination of both hard and soft targets up to release altitudes of 15,000 feet and a minimum terminal velocity (T.V.) of 850 feet per second (f.p.s.). The initial trials of the 30 lb. L.C. indicated the improbability of its ever satisfying these conditions.

Firstly in wind tunnel tests at the Royal Aircraft Establishment (R.A.E.), at Farnborough it was found that the T.V. was only 535 f.p.s. and nose-fairings had to be adapted to bring this above the required minimum of 850 f.p.s. Secondly, contradictory results were obtained on dropping tests, erratic ballistics seemed still to result no matter what modifications were made to the carriage and fuze attachment and, to further complicate matters, the bombs behaved differently when released singly or in salvo.

At a meeting at the Air Ministry in October 1936 the Porton representative stated that: 'as long as the fuze worked correctly the tail ejection design was satisfactory for dropping on soft targets, such as grass land up to 5,000 ft.'[2] This was far below the specified height but it was reasonable to assume that a bomb which could stand up to impact with a hard target from 15,000 feet would not only need strengthening, with the consequent reduction of the charge/weight ratio by about 50 per cent., but also when dropped on soft targets would penetrate too deeply for efficient functioning, and this in turn was contrary to Air Staff requirements.

Between late 1936 and early 1938, numerous attempts, made to arrive at a satisfactory compromise, culminated in a series of trials during March of the same year with a fully modified bomb released from heights between 5,000 and 10,000 feet. The results showed no improvement for the years effort, and because of the urgency now associated with production, it was decided to complete the design using the tail ejection principal only.[3]

The design having been decided, a number of essential tests still remained. Some of these, notably 'climatic' and 'keeping' trials, were necessarily of long duration, and in March 1938 apart from the production orders, a further order of five hundred 'experimental' bombs was placed.

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[1] A.M. File S. 37570/1.
[2] A.M. File S. 22603/2.
[3] A.M. File S. 37570/2.

The 250 lb. L.C. bomb

It is convenient, and advisable from the point of view of clarity, to leave the 30 lb. L.C. at this juncture in the process of manufacture, and to review the larger bomb.

Although some thought and attention to the production of a larger L.C. bomb had been given prior to 1935, it was not until October of that year that it became an Air Staff requirement.[1] Its conception was heralded by the introduction into the service of new and faster aircraft capable of carrying larger and heavier bomb loads a much greater distance than hitherto. In 1935 also, the commencement of the R.A.F. expansion enabled those concerned with L.C. bomb development to go ahead with ideas engendered by earlier trials with the 50 lb. bomb.

Tail ejection, with a view to overcoming the 'soft target' difficulties was again specified, but, as was to be expected, had its limitations. Experiments at Porton, with regard to soft targets, showed that if the bomb was allowed to come to rest before the blowing charge was ignited, the liquid gas was ejected through the bomb crater causing gross contamination over a considerable area with large drops, but wasting a quantity of the liquid within the crater itself, whereas, when instantaneous or short delay action was used, the liquid was dispersed in such fine drops as to be useless. It was also found that when dropped on semi-soft targets, such as shingle, the bomb broke up and contamination was by splash only.[2]

Trials during 1936 showed that the requirement to operate between 250 and 15,000 feet on hard or soft targets, in hot or cold conditions, with a minimum terminal velocity of 750 f.p.s. could never be met with the present 250 lb. design. Accordingly at an informal meeting between the Director of Armament Development (D.Arm.D.), the Chemical Defence Experimental Station, Porton (C.D.E.S.), and the Design Department at Woolwich in October 1936, it was decided to proceed with a new design to satisfy the original conditions and additional Air Staff requirements—dive bombing from 6,000 feet with release at 2,000, an increased minimum terminal velocity of 850 f.p.s., no predetermined level bombing release height, a detachable tail unit, and the ability to perforate the half-an-inch mild steel deck plates of Merchant ships.[3]

Initial dive bombing trials, carried out with the original bomb, now termed the Mark I, against a concrete slab at Porton, were inconclusive due to the smallness of the target and the consequent few hits obtained. At the end of 1936, probably when precision became urgent, the Assistant Director of Research and Armament Development, on the assumption that an 'inefficient' bomb was better than no bomb at all, ordered the production of 11,000 of the Mark I design.

Efforts to enlarge the Porton concrete target to twice its original area met the usual financial stumbling block, and it was not until June 1937 that sanction was given and further trials commenced. The standard Mark I, and a special bomb having a flat nose, were tested in single-release dive bombing from 6,000 to 2,000 feet, and although both types broke up on striking with a S.V. of 500 f.p.s., an area of between 200 to 300 square yards was contaminated

[1] A.M. File S. 35558.
[2] A.M. File S. 36720/1.
[3] A.M. File S. 40390/1.

in each case. Strikes on the surrounding grass land with the flat nosed bomb, showed a marked improvement over the standard Mark I, its' penetration being some 40 per cent. less.[1]

June 1937 saw the first deliveries of the 11,000 empty bomb order, and it was realised that manufacturing concessions, given without reference to Porton, were responsible for the production of a bomb much weaker in construction than those on which experimental work was proceeding. This caused considerable delay and to enable trials to continue, twenty-four round-nosed, and twelve flat-nosed bombs, were ordered from one contractor to be made exactly according to the instructions issued previously for the experimental bomb. Trials commenced at Porton in January 1938 with the specially ordered bombs released from 10,000 feet. From the results it was estimated that, with a different method of welding to prevent the main weld splitting on impact, good contamination could be expected on soft targets in approximately 50 per cent. of cases, and a useful degree of contamination from the remainder.[2]

Meanwhile the proposed 250 lb. bomb, Mark II, had been held up pending recommendations from development experience with the 30 lb. and the 250 lb. Mark I. Tentative designs had been produced in early 1937 and in July of the same year, considerable assistance resulted from an Air Staff decision to delete perforation of half-inch plate from a new list of requirements.[3] Before final designs were produced, it was decided to await the results of numerous modifications being tested on the 30 lb. bomb, and these were still outstanding when, in April 1938, it was decided to base the new 30 lb. design, and the 250 lb. Mark II on the tail ejection principle.

As the trials proceeded the urgency for production grew, and in January 1939, at a meeting of the R.A.F. Gas Development Committee, it was agreed that the Mark II bomb should be similar to the Mark I, except for a number of structural modifications, and would not incorporate any new principles.[4] Thus after a comparatively short development life, the design was decided; approval followed in March and two months later production orders were placed.[5]

During this manufacturing period, it was decided that some indication of performance against a more representative target was desirable. A suitable target was found in the disused Power House at Gretna Green; a three storied building having a 9 inch ground floor, a 6 inch intermediate, and a 4 inch top floor, all constructed in concrete. Its roof was made of wood and slate and apart from the small danger area available, which limited the maximum bombing height to 6,000 feet, was eminently suitable for the purpose.

Trials against this target commenced in April 1939, with bombs charged with the Mustard substitute—Methyl Salicylate. Bad weather unfortunately prevented release from all but the lower heights, so although satisfactory, confirmation was desired from a higher altitude, and in July of the same year a further series of full scale trials took place. On their report on the first series of trials, the Ordnance Board gave the bomb as functioning well under all the conditions tried against the target: penetration and subsequent

[1] A.M. File S. 39102.
[2] A.M. File S. 36720/3.
[3] O.C. Memo. B. 34750.
[4] A.M. File S. 40390.
[5] A.M. File S. 40390/2.

functioning was good and the resultant contamination heavy. It was probable, the report concluded, that rooms receiving the contents of the bombs would be uninhabitable to unprotected persons for some weeks or even months unless extensive repairs were undertaken ; vapour would probably render the building uninhabitable unless those parts affected could be isolated.[1]

The conclusions from the July trials from 6,000 feet not only confirmed these probabilities, but added that penetration of slate and timber roofs was easily accomplished and that, although no direct hits on the 4 inch concrete upper floor had been obtained, it appeared that this also would be penetrated.[2]

Little now remains to be recorded of either the 250 lb. or 30 lb. development : the worsening of the political situation during 1939 naturally hastened their final development. Briefly to summarise this period ; a new Air Staff requirement for functioning from 50 feet did not materially affect the 250 lb. bomb, but showed that the fuze with which the 30 lb. was fitted was not sufficiently sensitive, and, pending a modified design, 60,900 bombs of this weight were ordered in June with first deliveries anticipated in July. Thus by November 1939 stocks were building up but as yet no fuze was available.[3] In the absence of a suitable fuze, the 30 lb. L.C. was accepted as a 'break-up' bomb and charged missiles were cleared for sending overseas.

By May 1940, the fuze situation had improved, but in the meantime the Air Staff had accepted the old type and ensured its functioning by increasing the minimum dropping height to 250 feet.[4] Thus the only apparent problem remaining in 1940 was the old one of preventing excessive penetration of soft targets. Delay action parachutes and drogues were suggested but for many reasons proved only partially successful.

The Air Staff decided in June 1941 that the mustard H.S. filling should be replaced with phosgene, and all production above the phosgene requirement (30,000 to 40,000 per quarter), be filled with an incendiary mixture of rubber, phosphorus and Benzol.[5] In the same month, Porton reported that large scale trials had conclusively proved that, above a release altitude of 1,000 feet on to soft targets, tail ejection was unreliable and suggested that this could be rectified by adaption of an H.E. exploding system which had given a reliable and reasonable performance from all heights.[6]

The situation was finally cleared by the Air Staff in October 1941 with the decision that all charged 250 lb. L.C. bombs be reserved for use against hard targets where accuracy of aim was required, and that all other requirements would be filled by the introduction of the new 65 lb. L.C. bomb.[7] The 30 lb. bomb fared a little better ; by August 1940 the Royal Aircraft Establishment at Farnborough had evolved a new type of nose cap and retarding plate to restrict penetration, which, on tests during the next month, gave considerable satisfaction in that, apart from a small sacrifice in accuracy, it allowed releases from high altitudes into soft targets and increased the area of contamination.[8] Pending performance figures against a well constructed roof, 50 per cent. of

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[1] Ord. Board Report No. 2/39.
[2] Porton Departmental Report No. 81.
[3] A.M. File S. 37570/5.
[4] A.M. File S. 37570/8.
[5] A.M. File S. 40390/6.
[6] Porton Report No. 2277.
[7] A.M. File S. 40390/8 and M.A.P. File S.B. 19500.
[8] A.M. File S. 37570/9.

the 30 lb. order was modified to include the Farnborough attachment, and before the end of 1940, orders totalling 75,500 Mark I, 30 lb. L.C., and 26,000 Mark II 250 lb. L.C. had been placed with a number of manufacturers.[1]

Thus Air Staff requirements had eventually been 'met' by compromise, and it is interesting to note that the problem of soft target penetration was eventually solved by a reduction in terminal velocity, with an acceptance of a degree of inaccuracy, and that increased T.V., to simplify aiming and consequent accuracy, was proved impracticable.

The 65 lb. L.C. bomb

The 65 lb. L.C. bomb was evolved by the Chemical Defence Experimental Station at Porton during the time when delays were occurring in the development of the 250 lb. L.C. due to structural weaknesses. It was a cheap tin-plated bomb, based in design upon the square 4 gallon petrol can. With a small flag attached, to act as a stabiliser, the terminal velocity approximated to 300 feet per second, and dropping trials on hard, semi-hard and soft targets, as well as showing satisfaction, had produced an area of contamination at least equal to that of the 250 lb. bomb.

The realisation that a bomb of this type would be far short of the Air Staff requirement, particularly as regards 'service life', penetration and accuracy of aim, did not deter the Director of Armament Development (D.Arm.D.), from asking the Air Staff in May 1941 to approve its introduction into the service for use against targets other than modern buildings.[2]

By July of the same year, after a method of strengthening the 'can' had been devised and loading and handling trials carried out, the design was approved and provisioning commenced. Porton, in anticipation of its immediate approval, had already ordered 5,000 to be manufactured and calculated its life to be only nine months when a filling of a form of mustard known as mustard H.T. was employed.

Difficulties arose towards the end of 1941 when it was discovered that the bomb was totally unsatisfactory on soft targets when its contents were frozen solid. Several methods were proposed to deal with this difficulty, but the majority proved either impracticable or too costly, and in November of the same year, experience in manufacture, charging and handling, in addition to the desirability of including a simple burster charge to overcome the freezing problem, necessitated the preparation of a Mark II design.[3]

Basically the Mark II was similar to the Mark I. In form the only difference to be seen was the deletion of raised panels on each side of the bomb thereby preventing the development of very fine cracks at their edges which, because of the continual movement of the fluid contents and uneven stresses on the 'can' during transit, were apt to occur in the Mark I. A third handle was added to facilitate ease of handling, and a centralised filling hole, plus a redesigned filler cap with a fixed tommy-bar and extra washers were provided to ensure positive tightening and prevention of leaks in storage. The new type of filler cap allowed for a simple burster to be screwed in its place if required.

During January, February and March 1942 it was decided to increase the storage life of the bomb by internal varnishing ; this of course involved removal

[1] A.M. Files S. 37570/8 and S. 40390/1.
[2] M.A.P. File S.B. 18341/1.
[3] M.A.P. Files S.B. 18341/4 and S.B. 33572/1.

of the internal tin plating, but it was estimated that the whole process would increase the storage life of the bomb by about thirty-six weeks in the tropics, and from one to one and a half years in temperate climates.[1]

The design of the Mark II bomb was sealed in May 1942,[2] and a month later Bomber Command reported that from their investigations, the only practical method of obtaining reasonable accuracy of aim was that used when incendiaries were required to be dropped on the same target as high explosive.[3] Analysis of trial results, using this method, produced a 'mean point of impact' error in the order of 200 to 300 yards on releases at altitudes of between 1,000 and 10,000 feet.[4]

Development of the 65 lb. L.C. bomb after this stage, was mainly concerned with further trials on cooled and semi-cooled fillings and their respective contamination efficiency, and with 'weathering' the exterior to improve their storage life. These trials were naturally of long duration and continued until July 1944 when development of light-case bombs for the Royal Air Force virtually ceased.

The 500 lb. L.C. bomb

Although Air Staff had decided in 1937 that for many reasons liquid mustard gas was the only practical filling for light-cased aircraft bombs, the way had been left open for investigations into the alternative use of phosgene for retaliative purposes, should such a gas be used against us in a future war.[5] The Chemical Defence Experimental Station at Porton had therefore undertaken a series of tests and trials using the Mark I 250 lb. L.C. bomb charged with phosgene, and thus, by the time such a bomb came to be seriously considered by the Air Staff, a large quantity of information on the condition of use, possibilities of active employment, densities of contamination and lethality had accumulated.

In February 1941 the Air Staff asked the Director of Armament Development to make preliminary investigations into the quantity of phosgene which could be contained in a bomb capable of stowage on a standard 500 lb. bomb carrier.[6] Towards the end of the month, a preliminary design having been produced, the project was discussed in detail and the decisions and recommendations resulting were reported to the Air Staff.

The requirement consequent upon this report was formulated in April of the same year and a suitable design to meet these requirements was produced. One hundred bomb bodies were already on order by September 1941 when the minimum release height for functioning was reduced to 50 feet.[7] This brought forward the serious problem of danger to the dropping aircraft by ricochet, and other suggested methods having been shown as impracticable, D.Arm.D. arranged for the incorporation of delay detonator which could be selected before take-off. Despite this set-back, outline sketches of a suggested design were sent to contractors having had previous experience with this type of work, towards

[1] M.A.P. Files S.B. 33572/1 and S.B. 35053.
[2] M.A.P. File S.B. 33572/2.
[3] To allow for excessive ground lag the bomb aimer took aim at the target with his bombsight set for the release of a normal bomb of known ballistic performance. At a calculated time after release of the normal bomb would have occurred the gas bombs were dropped.
[4] M.A.P. File S.B. 33572/4.
[5] M.A.P. File S. 45638/1.
[6] M.A.P. File S.B. 15993/1.
[7] M.A.P. File S.B. 15993/1 and A.M. File C.S. 8912.

the end of November 1941,[1] and an urgent order was placed with one of the firms for ten unmodified bomb bodies for methods of fusing trials. Later in the same month a further one hundred bomb bodies were ordered from another firm to include a minor modification which they had suggested.

The trials in February 1942 of the first ten bombs ordered were inconclusive, and in March a list of tests was prepared which it was necessary for the phosgene bomb to pass before being recommended to the Air Staff for approval. C.D.E.S. Porton having carried out these and many other trials, including free release from altitudes ranging from 50 to 15,000 feet, gave a 'completely satisfactory' report, and in June 1942 the bomb, now known as the 500 lb. L.C. Mark I[2] was accepted by the Air Staff for introduction into the service.[3]

Full ballistic trials followed its acceptance, and by October of the same year it had been established that the bomb had good and consistent ballistics and a terminal velocity of 1,290 feet per second. Apart from some minor modification to allow for stowage in American aircraft, this concluded the very rapid development of this particular bomb and although it was never used for its designed purpose operationally, the work and research carried out on it, and in fact the whole series of gas bombs, was by no means wasted for it proved equally useful in incendiary and fire bomb development.[4]

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[1] M.A.P. File S.B. 15993/1.

[2] 'Mark I' was designated in order to avoid confusion when it was found that stowage dimensions limited the weight to a little under 400 lb.

[3] M.A.P. File S.B. 15993/2.

[4] *See* Chapter 6.

CHAPTER 8

ARMOUR PIERCING AND SEMI-ARMOUR PIERCING BOMBS

Early history

Before a study can be made of the history of the ' piercing ' type of bomb, it is necessary to review the background under which such a requirement became apparent.

Following the First World War, investigations into the results of bombardment of enemy ships and 'armoured' land targets with armour piercing projectiles, showed the need in future conflicts for an aerial missile capable of piercing the protective covering of possible targets and exploding after penetration.[1] It was with this view in mind that the Design Department produced in 1921, a proposed design of an armour piercing bomb 11 inches in diameter and weighing approximately 750 lb. The design was based on an assumed release height of between 6,000 and 8,000 feet from which height it was calculated that it would penetrate a 3 inch hardened steel plate with a striking velocity between 700 and 750 feet per second (f.p.s.). Copies of this design were sent to a number of firms experienced in the design and manufacture of A.P. projectiles inviting comments, drawings, specifications and quotations for an A.P. bomb on the lines indicated in the sketch.[2]

Development 1922 to 1930

By February 1922 four designs had been submitted and these, together with a modified Air Ministry design, were discussed at a meeting called by the Ordnance Committee on 13 March 1922 to investigate R.A.F. requirements for A.P. bombs. At the meeting the Deputy Director of Armament Research envisaged the probability of limiting the maximum weight of an individual bomb to 500 lb., and on this assumption, the Superintendent of Design Naval Ordnance (S.D.N.O.), was requested to prepare copies of the designs of the 11 inch bomb proportionally reduced to weigh approximately 435 lb., and adapted for firing from a 9·2 inch gun, in order that bombs could be ordered for recovery, plating and fragmentation trials.[3]

In the April of the same year the Chief of Air Staff agreed to the proposals[4] and three designs of bomb with varying explosive capacitites of 6 per cent., 13 per cent. and 19 per cent. were forwarded to the Ordnance Committee. The first represented a bomb of the smallest acceptable capacity, the second a bomb of the maximum practical capacity, and the third, prepared only for comparison,

[1] There was produced for the Royal Naval Air Service towards the end of the First World War an alleged armour piercing bomb of 180 lb. weight. A few of these weapons were dropped against the *Goeben* in the Dardanelles in 1918, but needless to say without any effect. The bomb was pear shaped and made of cast steel, and perhaps its most interesting feature was that it was fitted with a form of penetrating cap of fairly soft metal, which was alleged to ' lubricate ' the passage of the bomb through armour.

[2] A.M. File S. 19081.

[3] O.C. Memo. B. 4861.

[4] A.M. File S. 17413.

a bomb of the maximum theoretical capacity.[1] The bombs were shown fitted with a driving band to obtain rotation on firing, and for alternative use when rotation was not required, a design for a ' gascheck ' band was included.

The Superintendent of Design (S. of D.) was immediately asked to manufacture six 13 per cent. capacity bombs (three with driving bands and three with gascheck bands) for recovery trials to test the suitability of the design for subsequent plate penetration trials ; eight 6 per cent. capacity and eight of 13 per cent. capacity, for fragmentation trials to ascertain the velocity and armour piercing qualities of the fragments produced by detonation at rest in air and under water.

In the recovery trials, commenced in December 1922 at the Experimental Establishment at Shoeburyness, the bomb was fired so as to pass through ' jump ' cards placed at intervals of 10 yards from 20 to 100 yards from the muzzle of the gun, and by this means an appreciation of the trajectory and steadiness in flight, angle of strike and size of hole was obtained.[2] The recovered bombs, apparently undamaged, were sent to S. of D. for examination, re-hardening and re-banding in preparation for firing at hardened steel plate.[3]

In the meantime the fragmentation trials were proceeding with the remaining sixteen bombs. These were filled with an explosive mixture of 80/20 shellite, and 50 per cent. of each capacity were detonated at rest in air and the remainder at rest under water. The results were forwarded to the Ordnance Committee in May 1923, and showed that despite the fact that the 6 per cent. bomb contained a greater weight of metal, the fragments of the 13 per cent. capacity bomb were in fact larger, more numerous, and, for penetration and velocity, far more effective.[4]

The first plating trials (penetration of hardened steel plate) took place at Shoeburyness on 7 May 1923.[5] The bomb, one of 13 per cent. capacity, originally used for the recovery tests, was fired against a 3 inch nickel-chrome plate at normal with a striking velocity (S.V.) of approximately 700 f.p.s.[6] Penetration was achieved and the bomb was recovered apparently undamaged. The success of this one bomb, prompted a request to the Superintendent of Experiments (S. of E.) for a repetition of the trial with the remaining bomb, at a S.V. of 1,000 f.p.s. It was calculated that this speed would roughly correspond to a free release from 20,000 feet, and would give valuable data for future trials against concrete targets.

In a minute to D.D.R.(Arm.) referring to the trials, D.N.O. raised the question of the suitability of retaining shellite as the explosive filling, he pointed out that medical restrictions during manufacture, caused considerable complication and expense and suggested that T.N.T., with its many advantages, was worthy of consideration. Mainly as a result of this, further trials were suspended until the whole development programme had been discussed and re-organised.

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[1] O.C. Memo. B. 4944.
[2] O.C. Memo. B. 5618.
[3] O.C. Memo. B. 5663.
[4] O.C. Memo. B. 6046.
[5] O.C. Memo. B. 6108.
[6] At an angle of 90° to the ground, or such that the axis of the bomb was at right-angles to the plate at the moment of impact.

A meeting for this purpose was called at the Admiralty on 2 July and the following trials agreed :—[1]

(*a*) Plating trials against 3 inch plate at 20° to normal to be repeated at S.V.s of 700 f.p.s. and 1,000 f.p.s., and, if successful, repeated at the same striking velocities but with two ¾ inch plates at intervals of 8 feet before the 3 inch plate to represent the upper and main decks of a capital ship.

(*b*) Concrete targets to be constructed, but the trials against them deferred until it was possible to use filled and fused bombs.

As regards the filling, it was decided that of the three explosives considered—shellite, T.N.T. and amatol—T.N.T. was the most promising, and for the fuze a tail detonating type with a delay of 30 feet after penetration of ¾ inch plate was required. Financial approval for the trials and manufacture of six bombs was obtained by 27 August 1923, and the trials themselves were carried out on 4 December 1923 with complete success.[2]

It was decided therefore to repeat the trials against 4 inch plate,[3] and, in addition, to fire one bomb at 3 inch plate with a S.V. of 600 f.p.s. representing a free release from 6,000 feet, from which height an increased percentage of hits was possible.[3] The trials, which were completed during July and August 1924 showed that at S.V.s of 700 f.p.s. against 4 inch plate and 600 f.p.s. against 3 inch plate the bomb penetrated the ' upper deck ' but rebounded whole off the ' main deck,' whereas at 1,000 f.p.s. penetration of upper and main 4 inch decks was achieved, but on passage through the 4 inch plate the tail end containing the adaptor broke completely away from main body of the bomb.[4] These results established the limits of the penetrative powers of the bomb in given conditions of height of release, speed and angle of strike, and amount and thickness of armour, and, moreover, brought into prominence an hitherto unknown weakness in that portion of the bomb designed to contain the means of initiating detonation.

Thus the first and major phase in the design and development of an A.P. bomb, its power of penetration and fragmentation, was complete, but it has no doubt been realised that throughout the trials the bomb as a missile to be dropped from an aircraft, was virtually non-existent.

The evolution of the air missile, however, had not been forgotten. The Royal Aircraft Establishment at Farnborough (R.A.E.) had for some time been experimenting with model bombs in a wind tunnel to discover the best ballistic shape ; D.D.R. (Arm.) had received, rejected, altered or modified a number of tail unit designs, and tested a much larger number of proposed fuzes ; investigation had been made into methods of attachment and release from aircraft until finally only full ballistic dropping tests and the trials, previously arranged against concrete targets, were awaited.[5]

Considerable thought and energy had to be devoted to this final stage in design with the result that, in November 1925 after satisfactory ballistic trials, it was agreed, on the recommendations of D.D.R. (Arm.) and D.N.O., to cancel

[1] O.C. Memo B. 6265.
[2] A.M. File S. 19081 and O.C. Memo. B. 6759.
[3] O.C. Memo. B. 6848.
[4] O.C. Memos. B. 7664 and B. 7799, I and II.
[5] The 9·2 inch bomb as fired from a gun, was fitted with a tail adaptor which combined with a driving or a gascheck band was to be equal in weight to their air missile replacements—a fuse and tail unit.

all further proposed plate trials and accept the bomb into the service.[1] S. of D. prepared the designs which were sealed under the title of ' Bomb, A.P., 450 lb., Mark I '.[2]

The series of trials against reinforced concrete planned to test depth of penetration and sensitivity of explosive contents and the various methods of filling, did not in fact proceed farther than the initial penetration trials. On these, which took place over the period from October 1925 to January 1926, the bomb proved satisfactory, and in view of future projected development of a 450 lb. Mark II and a 1,500 lb. A.P. bomb, acceptance was given with a T.N.T. filling, the sensitivity and best method of filling of which was already well known.[3]

This and the sealing of design did not, however, decide the ultimate form of the bomb, and it was not until 28 August 1928 that the bomb specification actually appeared. Small orders had been given to various private firms in order that they might gain some experience in its manufacture, and that some estimation of time and cost of manufacture might be gained should an urgent requirement arise.[4] The bombs thus produced were subjected to radiological examination and tested for method and efficiency of manufacture in another series of plate trials. A ' tear-off ' base[5] replacing the driving band enabled a true estimation of the strength of the tail portion and the modification necessary to prevent loosening, or squeezing out of the tail adaptor during penetration.

The Mark I bomb made its final appearance in Naval trials between September and November 1930 to test the efficiency of new strengthened deck armour and fragmentation effectiveness in between-decks detonation.[6]

The story of the 450 lb. Mark I bomb has been written in some detail in order to illustrate the various stages necessary in the development of an A.P. missile, but the reader must realise that each stage in the evolution of both the bomb itself and its constituent parts entailed thought and experimentation of far too wide a nature to be adequately covered in this narrative.

Other armour piercing bombs and the semi-A.P. series were developed in similar fashion, and the remainder of this account will deal in the main with a brief chronological record of changing requirements and salient points in the evolution of these bombs.

Mention must first be made, however, of the Mark II 450 lb. A.P. bomb ; it was in fact a modified Mark I evolved in order to overcome the weakness inherent in the tail portion. Designs were in hand in 1928, but low priority was given to sealing and manufacture until September 1930, when it was considered by the Assistant Director of Armament Research and Development, previously D.D.R. (Arm.), that existing stocks of the Mark I design would be unsuitable for proposed ship trials against H.M.S. *Marlborough*.

From the point of view of the 450 lb. Mark II bomb, the trials proved of little value. Admiralty fears of a negative result due to the possibility of the bomb sinking the ship, prevented a ' live drop,' and only one Mark II was used,

[1] A.M. File S. 19081.

[2] The nominal increase in weight from 439 to 450 lb. given in the title, involved no actual change in weight but was given in order to allow a safety margin, and to facilitate ease in calculation of maximum aircraft loads.

[3] O.C. Memos. B. 9491 and B. 10156.

[4] A.M. File S. 25078/1.

[5] The ' tear-off ' base was designed to be torn off during penetration of the first plate thereby removing a possible extra cause of weakness in the tail portion.

[6] O.C. Memos. B. 20127, B. 21316, B. 21414 and B. 21574.

and that detonated at rest in an unfavourable situation between decks.[1] The design and method of filling was finally approved by A.D.R.D. (Arm.) in March 1932,[2] but in the following July the Air Staff agreed that the requirement for this bomb had ceased to exist and the whole 450 lb. A.P. series was abandoned.[3]

The 1,500 lb. A.P. bomb

With the alterations which were taking place in battleship deck construction, it became obvious during the trials of the 450 lb. A.P. bomb that a more powerful weapon would soon be required, and as early as 1924 models of larger bombs were constructed and underwent a series of ballistic tests. Thus when a Naval requirement was formulated for a bomb capable of perforating 7 inch hardened steel plate at 10 degrees to normal, designs based on model ballistics were soon prepared for a bomb weighing 1,500 lb. which, it was calculated, would achieve the necessary penetrating velocity of 750 f.p.s. on a free release from 10,000 feet.

The initial order for four weighted bomb bodies was placed with the Royal Ordnance Factory at Woolwich in November 1926 and followed, early in 1927, by similar orders with the firm of Firth and Hadfields Ltd.[4] The bombs were adapted for firing from a 15 inch 'Breech-Loading' gun and trials against 7 inch nickel-chrome plate, with the first two bombs, were held at Shoeburyness on 27 and 29 July 1927. The results were unsatisfactory in that although the bombs penetrated the plate, they failed to perforate it and rebounded whole.[5]

The manufacturers of these two bombs, in a letter to the Ordnance Committee, suggested that out of four alternatives which they listed, the only feasible method of obtaining performation with a bomb of 1,500 lb. weight in the given conditions, was to reduce the diameter from 15 inches to 12 inches and make up the lost weight by increasing the length of the bomb. They attached two sketches of a proposed design and later, on request, a further design for a 15 inch diameter bomb weighing approximately 2,000 lb.

The plate tests of the first two bombs had shown quite plainly that although the strength of the bomb was adequate, it could not perform the task for which it was designed, and after considerable inter-departmental correspondence and discussion, a meeting was called to discuss future A.P. bomb policy. At this meeting, held at the Admiralty on 18 January 1928, it was decided to redesign the bomb to weigh 2,000 lb.[6] Trials with the 1,500 lb. size would continue to determine its actual plate performance and thereby collect data of value for the new design. S. of D. was asked to prepare, for future use, two 2,000 lb. bomb designs of 8 per cent. and 10 per cent. explosive capacity and with differing degrees of 'sharpness' of nose.

Trials during 1928 established that the 1,500 lb. bomb would perforate 6 inch N.C. plate set at 10 degrees to normal at a S.V. of 814 f.p.s.; 20 degrees to normal at a S.V. of 850 f.p.s., and 3 inch N.C. plate (main-deck thickness of the majority of battleships at that time), at 20 degrees to normal with a S.V. of 561 f.p.s., representing a free release from 5,000 feet. Although this did

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[1] A.M. File S. 31270.
[2] A.M. File S. 3046.
[3] A.M. File S. 17413.
[4] A.M. File S. 24988/1.
[5] O.C. Memo. B. 13557.
[6] O.C. Memo. B. 14768.

not meet the original requirement, it was decided at the Annual Bomb Conference of 24 July to seal the design in preparation for the manufacture of a reserve of bombs pending the 2,000 lb. development; plate and fragmentation trials were however to continue.[1]

Two bombs filled with T.N.T., by two different methods, were employed in successful under-water fragmentation trials at Shoeburyness in June 1929, and in further plate trials in the same year, it was established that the bomb when dropped from 3,000 feet could be expected to defeat 3 inch N.C. plate. From model ballistics and experience gained on the 450 lb. project, it was concluded that provided the centre of gravity was kept within known limits a good air performance was assured, and for this reason, actual dropping ballistic trials were not considered necessary.

Although shape and penetration had been satisfactorily proved this did not mean the end of trials, and the remainder of 1929, the whole of 1930 and most of 1931, was taken up with further plate trials, an unsuccessful insensitivity trial, designing, testing and approving minor modifications and numerous other items such as—the form and material of the tail unit, the fuze, the exploder container, adjustment to fit 'carrier' bomb hoists, type of bomb carrier and methods of bomb attachment and release from aircraft, rough usage trials, and even methods of packing for transportation were investigated.[2]

November 1931 saw the cancellation of the previously sealed design and production of another with all the amendments and modifications incorporated; only a design to cover the method and type of filling was still outstanding and in this condition the 'empty' design of 'Bomb Aircraft Armour Piercing 1,500 lb. Mark I' was approved and sealed.[3]

Nothing further was heard of this bomb until June 1941 when the Admiralty suddenly requested that twenty bombs should be manufactured for trial purposes. At this stage during the Second World War, manufacture of 1,500 lb. bombs would have seriously interfered with the 2,000 lb. production programme, and in August that year the Admiralty withdrew the request but asked that the design might be cleared for production at a later date. In consequence a series of meetings was held at the Ordnance Board (O.B.),[4] and arrangements made for clearing the design for manufacture and trials. In October 1942, however, the Naval Staff stated that their requirement would be met by either the 2,000 lb. A.P. or the American 1,600 lb. A.P. and the 1,500 lb. development item was deleted from the programme.

The 2,000 lb. A.P. bomb

The failure of the 1,500 lb. bomb to fulfil the Naval Staff requirement involving perforation of 7 inch N.C. plate, resulted, it will be remembered, in a conference at the Admiralty on 18 January 1928 at which it was decided to ask S. of D. to design a bomb to weigh approximately 2,000 lb. and thereby to obtain perforation by means of this added weight.[5]

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[1] O.C. Memo. B. 18623.
[2] A.M. File S. 24988/2.
[3] A.M. File S. 24988/3.
[4] O.B. Proc. No. 20321. Name changed from 'Committee' to 'Board'—January 1939.
[5] O.C. Memo. B. 14768.

Four designs of such a bomb, differing only in explosive capacity and the degree of 'sharpness' of the nose (C.r.h.),[1] were forwarded to the Ordnance Committee in March of the same year and it was recommended that, in view of experience gained in the past, bombs of 2, 3 and 4 C.r.h. be manufactured for trials against 7 inch and 3 inch plates at angles to normal of 10 to 20 degrees, and at striking velocities of 800 and 520 f.p.s. respectively,[2] also that S. of D. be asked to prepare additional designs for a similar bomb of 2½ C.r.h.[3] These latter designs were soon forthcoming and, in January 1929, the contracts already placed for two bombs of each type were amended to include a further two bombs of 2½ C.r.h.

Due to the multiplicity of the trials at varying S.V.s, angles and thickness of plate and constant comparative repetition with differing nose construction and manufacture, it was not until December 1929, with the initial deliveries still awaited, that the performance of the bomb was thought promising enough to consider the tail unit and complete bomb ballistics.[4] Briefly, these trials held during the months of August, September and October 1929, established that the most promising nose construction was that of 2½ C.r.h., with a critical perforation S.V. of 727 f.p.s.[5]

It was estimated that in order to complete outstanding trials necessary before the bomb could be accepted into the service, twelve more bombs, in addition to those previously ordered, would be required, and to this end orders for four bombs each of 2½ C.r.h. were placed early in 1930.

The first two bombs of the original order were delivered and used in manufacture comparison trials in January and February 1930. Both these bombs, a 2 C.r.h. and a 2½ C.r.h., confirmed previous satisfaction by successfully defeating 7 inch plate at a speed of approximately 730 f.p.s. and, in view of this confirmation, it was decided to accept theoretical plate performances from higher altitudes of 10,000, 12,000, and 16,000 feet, and investigate the minimum height for perforation of 4 inch N.C. plate.[6]

Deliveries of the 2½ C.r.h. orders started to arrive in September 1930 but in the intervening months a decision to use a steel exploder container instead of one made of paper, adversely affected the total weight of the bomb and made redesign to counteract this necessary. This involved more ballistic trials with scale models of the bomb and resulted in a different shape and size of tail unit. Attachment to the aircraft bomb carried was to be accomplished by means of steel straps, but a lifting-eyebolt to provide a satisfactory means of handling the bomb had to be introduced. Finally, the unsatisfactory insensitivity results of both methods of T.N.T. filling used in the 1,500 lb. bomb prompted the decision to use a shellite as a temporary filling for the 2,000 lb. series and arrangements were made for an insensitivity trial with one of Hadfield's original 3 C.r.h. bombs shellite filled.[7] This trial against 7 inch plate did in fact take place on 27 March, and was completely successful.[8]

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[1] C.r.h., 'Calibre Radius Head'—the radii of arcs struck from points perpendicular to the axis of the bomb at the commencement of the nose curvature, *e.g.*, 2 C.r.h. signifies a nose shape formed by arcs equal in radius to twice the diameter (calibre) of the bomb.

[2] O.C. Memo. B. 15178.

[3] A.M. File S. 27029/1.

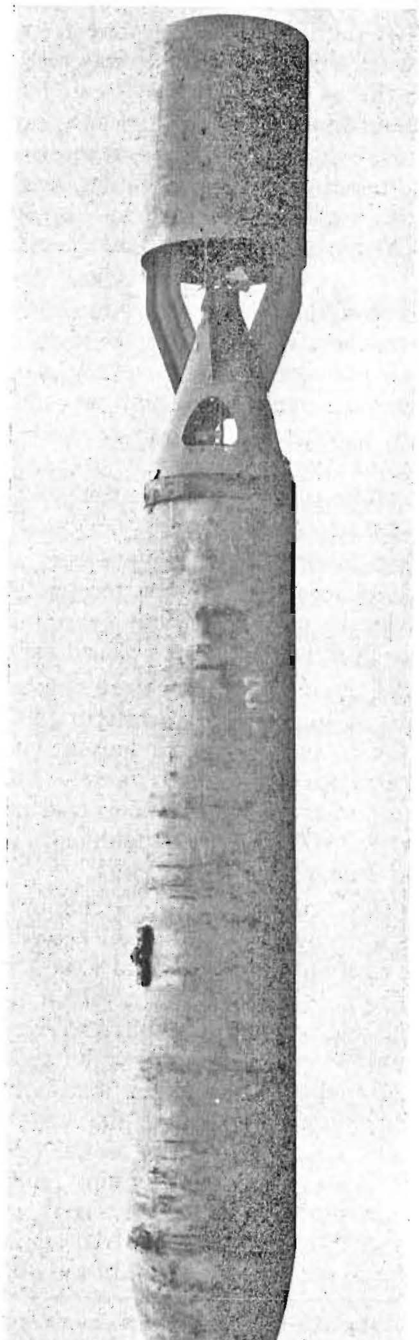
[4] O.C. Memo. B. 19123.

[5] O.C. Memos. B. 18737, B. 18949 and A.M. File S. 27029/1.

[6] O.C. Memo. B. 20178.

[7] O.C. Memo. B. 20754.

[8] O.C. Memo. B. 22468.



2,000 LB. A.P. BOMB. MARK IV

In the six months ending October 1931 all the outstanding trials of the Vickers Armstrong bombs and the 2½ C.r.h. trials against four inch plate, which ascertained a limiting penetration velocity of 470 f.p.s., were completed and in May 1932 the complete designs of the empty 2,000 lb. A.P. bomb were approved.[1]

Partly as a result of the trials against H.M.S. *Marlborough* previously mentioned and in vew of future bomb policy, an Air Staff decision of July 1932 to limit the weight of all individual aircraft bombs to a maximum of 500 lb. caused the abandonment of all A.P. bomb development.[2] It was not until four years later, with the improvements in aircraft and ship construction and development of new type bombsights, that the Air Staff became definitely interested in heavier piercing bombs, and on 31 May 1936 C.A.S. approved further development.[3] In the following month this was augmented by the decision to adopt the 2,000 lb. size as the heavy piercing bomb.[4]

From that date events proceeded with increasing speed, the Ordnance Committee was requested to initiate final development of the existing design to enable early production, and were faced with a formidable array of investigations which were essential before this stage could be reached.[5] Progress was impeded at an early date by the expression of serious doubt as to the bomb's ballistics and persisted until April 1937, when exhaustive trials on a half scale model at the Aeroplane and Armament Experimental Establishment (A. & A.E.E.), at Martlesham Heath, established satisfaction in this respect. Two months later a contract for a limited supply was placed, and in March 1938 ballistic satisfaction was confirmed in full scale tests with an inert bomb.[6]

Although 50/50 shellite was originally an emergency filling, it was decided to accept this as the standard subject to satisfactory fragmentation trials. One bomb detonated at rest on 23 September 1939 was sufficient to prove complete satisfaction both for blast and fragmentation.[7] The next two years brought forth a mass of suggestions and counter-suggestions. Aluminium became scarce and caused redesign of the tail unit which advanced the design to Mark II. Production of the No. 37 fuze became difficult and a simple pistol and detonator was adopted. By the time redesign was complete, the fuze situation had improved and the No. 37 was re-adopted. Later in 1941 large scale production was ordered with a reversion to pistol/detonator fuzing, and in February 1942, after static detonation and dropping trials had shown the superiority of this type of fuzing, the Mark II bomb was introduced into the service.[8]

Further plate trials in June 1942, against a composite target representing the top and main decks of the German battleship *Tirpitz*, confirmed calculation that the bomb was capable of defeating such a target at a speed representative of a release from 4,000 feet.[9]

The final form of the bomb to be introduced into the service during October 1943, known as 'Bomb H.E. Aircraft 2,000 lb. Mark III', differed only from the Mark II in internal contour and a modified base adaptor. It had a filling of

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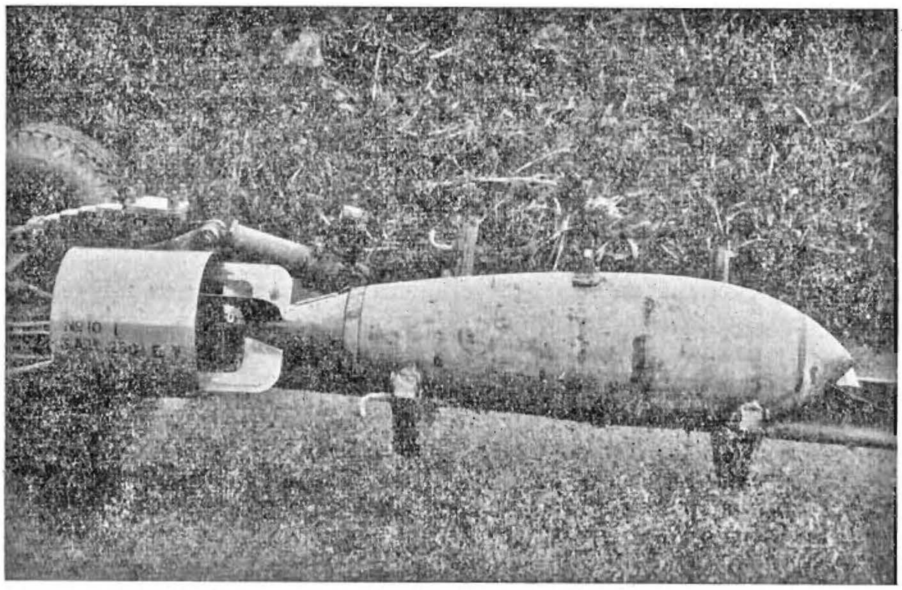
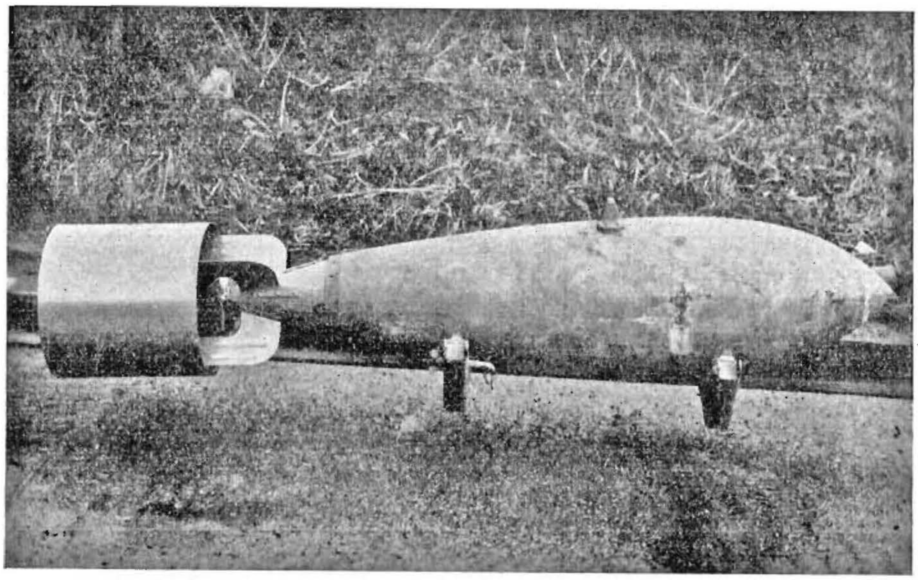
[1] O.C. Memos. B. 23274, B. 23435 and A.M. File S. 27029/2.
[2] A.M. File S. 17413.
[3] A.M. File S. 38401.
[4] A.M. File S. 27029/2.
[5] O.C. Memo. B. 23573.
[6] A.M. File S. 27029.
[7] O.B. Proc. 3779.
[8] A.M. File S. 27029/3 and O.B. Proc. 17736.
[9] A.M. File S. 27029/3.

70/30 shellite in place of the 50/50 previously. A Mark IV bomb was designed but due to its late arrival never came into service. There is no doubt that the 2,000 lb. A.P. bomb was, as a piercing weapon, a very fine technical achievement, and given a reliable fuzing system may have proved itself a very useful weapon.



250 lb. S.A.P. Bomb. Mark V



500 lb. S.A.P Bomb. Mark V

By July 1944 however, due mainly to its poor charge/weight ratio and the introduction of the large medium capacity and rocket assisted bombs further production was cancelled.[1]

[1] A.M. File S. 27029/4.

Semi-armour piercing bombs

To write in full the history from inception of the S.A.P. series, would be an almost verbatim repetition of the former A.P. account; sufficient to state therefore, that precisely similar trials and difficulties occurred and the only practical difference was the purpose for which the bombs were designed and the trials results. The requirement became apparent during the development of the 450 lb. A.P. bomb, when at a conference held at the Admiralty on 17 July 1924 the Air Ministry agreed to produce a new design for a 'general purpose bomb' with a solid nose capable of perforating one-and-a-half-inch plate.[1]

Subsequently it was decided to develop two new types of bomb—a 250 lb. and a 500 lb. for use against submarines and two of similar weight with solid noses for use against the decks of capital ships.[2] The Design Department was asked to prepare designs for the latter type which was to be of the general contour of the G.P. bombs already under development, and to be capable of perforating one-and-a-half-inch deck plates without breaking up. The bombs were to be filled with grade I T.N.T. and fuzed to detonate at an average distance of four feet after perforating the first deck of one inch or greater thickness. A short exploder was to replace the central tube if the efficiency of manufacture did not suffer thereby. Sketch designs were forwarded to, and accepted by the Ordnance Committee on 20 February 1925 and after minor internal modifications to the design, six 250 lb. bombs, now termed semi-armour piercing (S.A.P.), were ordered for experimental firing trials.[3]

During, June 1926, four bombs were fired from a 9·2 inch gun at one-and-a-half-inch plate with striking velocities corresponding to speeds obtained on free release from heights of 4,000 and 10,000 feet. The plates were at angles to normal of 10° and 20° and in all cases perforation was obtained. The success of these trials, coupled with the fact that the calculated velocities used were found to be slower than actual velocities by approximately 100 f.p.s., prompted further trials but this time against two-and-a-half-inch plate.[4] With the plate at 10° and a S.V. of 705 f.p.s. successful perforation was achieved; at 558 f.p.s. however, the bomb broke up on the surface of the plate and at both speeds with the plate at 20° penetration and rebound resulted.[5] The limits of plate perforation were thus established and late in the same year, 1927, after satisfactory insensitivity trials, the designs for both the 250 lb. and the 500 lb. were approved and sealed.[6]

It may be noted that the 500 lb. bomb did not figure in any of the above trials, it being reasonably concluded that the performance of the 250 lb. bomb would be at least equalled if not bettered by one of greater weight. The partial failure against two-and-a-half-inch plate however, brought with it a reason for testing the larger bomb in similar circumstances, and four 500 lb. bombs were ordered in March 1927 for the purpose.

These trials which took place at Shoeburyness in December of the same year against two-and-a-half-inch plate at 10° to normal, gave very similar results to

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[1] A.M. File S. 23219/1.
[2] O.C. Memo. B. 6873. *See* Chapter 3.
[3] O.C. Memo. B. 8481 and A.M. File S. 23955/1.
[4] O.C. Memo. B. 11045. Two and a half inch was considered to be the thickest deck protection of any foreign cruiser.
[5] O.C. Memo. B. 11966.
[6] A. M. File S. 23955/1. (Approval given by Director of Artillery at the War Office, who was at that time the only authority.)

those obtained with the 250 lb. bomb, in that perforation was achieved at 682 f.p.s., and penetration and rebound at 505 f.p.s. Satisfaction was expressed however, in that failure to defeat two-and-a-half-inch plate was no detriment to a bomb designed to perforate one-and-a-half-inch plate.

This virtually concluded the experimental development programme and from 1928 onwards trials were of a more confirmatory nature concerned with effectiveness and the production aspect. The S.A.P. series suffered from the same periodical considerations and difficulties which were affecting the A.P. project, so that in December 1927 owing to the possible shortage of forging capacity in time of war, a cast steel bomb was proposed and five bombs of each weight ordered for trials.[1] Later, in February 1928, orders were placed for cast steel and forged steel bombs.

The S.A.P. series was designed in the first instance to include a 'screw-in' type of fuze, but early in 1928 the Admiralty requested a 'fit-in' fuze which had a fixed position in relation to the bomb suspension lug. The modification entailed alteration of the tail unit, so, to lessen the total empty weight and thereby allow for an increase in weight of explosive, the tail unit was redesigned in duralumin. This of course altered the position of the centre of gravity and, to avoid changing the position of the suspension lug, which would have upset bomb carrier arrangements, the whole bomb was redesigned as the Mark II with internal weight added to bring the c. of g. within the limits, and thus preventing any increase in explosive capacity.

During 1928 and 1929 difficulties arose with the method of firing the bomb and much time was spent in testing various designs of centering rings, base adaptors, 'tear-off' and 'spring-off' bases, and the final proof of the bomb before introduction into the service was greatly delayed on this account. In June 1929 however, after many minor modifications the bomb was approved for manufacture,[2] and in the same month static detonation and fragmentation trials with the Mark I proved the suitability of either of the two methods of T.N.T. filling.[3]

Subsequent penetration trials with cast steel bombs proved them as efficient as those of forged steel, and with the success of both types and weights having exceeded the original requirement, it was decided that, provided the penetrative qualities did not fall below the one and a half inch requirement, a Mark III should be produced with an increased explosive capacity.[4] At this stage the proposed filling for Mark II bombs had not been tested for insensitivity, but the Admiralty's need for these bombs was urgent and D.N.O. agreed to accept them on previous T.N.T. filling experience. In March 1931 therefore, the Marks I and II of both weights, with fine grain T.N.T. fillings, were introduced into the service and production orders placed.

Between 1931 and 1933 insensitivity trials were almost continuous and resulted in the Ordnance Committee recommending that the 250 lb. S.A.P. be filled with a mixture of T.N.T. and a small quantity (7 per cent.) of beeswax or paraffin wax, and the 500 lb. S.A.P. with 'biscuit' or fine grain T.N.T.[5]

[1] O.C. Memo. B. 14413.
[2] A.M. File S. 23955/2.
[3] O.C. Memo. B. 18583.
[4] A.M. File 845071/28.
[5] 'Biscuit'—T.N.T. cast in square blocks about two inch by one inch and introduced into the bomb with T.N.T. warmed to the consistency of treacle. A.M. File S. 17413.

In spite of the time and labour spent in the development of this series of bombs, it was not until November 1934, ten years after its original conception, that service loading trials in H.M.S. *Courageous* revealed a weakness in the duralumin tail unit. This defect, and some uncertainty regarding supplies of aluminium in time of war, caused the Mark III to be designed with a steel tail unit, an increased explosive capacity, an improved exploder system, and a suspension lug strengthened to withstand the stresses of catapulting was also included. Its introduction into the service in February 1926 was rapidly followed by the Mark IV, which differed only in having a ' snap-on ' tail unit instead of the fitted and fixed type.

With the exception of a small number of bombs used in initial ballistic trials, the first occasion on which S.A.P. bombs were dropped from aircraft was in the trials against H.M.S. *Marlborough* in February 1932.[1] Both weights of the Mark II were dropped with very gratifying results, and after a second series of successful trials against the ' Chatham Floating Target ' (Job 74), no further level bombing trials were considered necessary.

The Admiralty, however, wished to study the effect against a typical ship target in diving attacks, and in September 1935, when an aircraft capable of diving with a 500 lb. bomb had been developed, trials with inert bombs were commenced. Success was once again achieved and in October 1937 level and dive-bombing trials with live bombs, to test deck and structural damage, were ordered.

By August 1938, ' Job 74 ' was withdrawn for repairs, which it was estimated would extend until early 1940, and on the declaration of war in 1939 the Air Ministry's proposed trials with the Research Development Explosive (R.D.X.) filling were abandoned.

The ultimate stage in S.A.P. development was reached in 1939, with the introduction of the Mark V S.A.P., which reverted to the simple pistol and detonator fuzing and an improved method of clipping on the tail unit.

Conclusion

Despite the time and labour spent in the development of the bombs reviewed in this chapter, it cannot be said that they were the success originally hoped for. They suffered from one serious defect—the weight of actual explosive compared with the weight of metal required to defeat the target.

Having achieved perforation, their blast and fragmentation effect was only sufficient to cause purely localised damage, it being doubtful whether a heavily armoured vessel could be sunk by one such bomb. Unless the ship was in fact sunk or damaged beyond repair, its ' out of action ' period did not permit deployment of forces to other theatres of war.

Viewing this in the light of the difficulties of obtaining a direct hit in wartime conditions, the fact that a broadside hit was unlikely to perforate, and that a near miss, unless it was within a very few feet of the ship's side, was unlikely to do any damage at all, it will be realised that the proposition was far from economic. Even allowing for the possibility of a direct hit, investigation into German battleship construction revealed that the vulnerable area had been substantially reduced due to increase in thickness and extent of armour protection surrounding the main armament. Against land fortifications and multi-storied buildings, perforation was possible in many cases, but actual destruction

[1] A.M. File S. 31270.

was problematic due once again to the poor blast effect on detonation. Thus the A.P. and S.A.P. series of bombs played only a minor part in the Second World War and in the majority of cases were used to supplement supplies of the larger and more powerful bombs.[1] For example, in the table shown below, comparison is drawn between the use of the 500 lb. S.A.P. and the 500 lb. M.C. bomb. The 250 lb. S.A.P. was used even less because by 1941, apart from its inefficiency, Air Staff policy had ruled out that particular size of bomb as being uneconomic.

The active limitations of the 2,000 lb. A.P. have already been discussed, and it is significant to observe that they did only slight damage to the German battleship *Tirpitz*, which was finally destroyed by the larger 12,000 lb. M.C. bomb (' Tallboy ').

Numbers of Bombs dropped in the Second World War

	S.A.P. 500.	*M.C.* 500.
1939	87	—
1940	160	—
1941	8,348	—
1942	2,830	636
1943	170	32,519
1944	17	238,362
1945	—	131,235
Total 1939/45	11,612	402,752

[1] *See* Chapters 10 and 13.

CHAPTER 9

THE CAPITAL SHIP (C.S.) BOMBS

On 16 January 1942, at the instance of Lord Cherwell, Scientific Adviser to the War Cabinet, a meeting under the Chairmanship of D.N.O. took place at the Admiralty to discuss a proposal that the Shaped Charge Principle should be applied to the attack of capital ships.[1] The main reason for the proposal was that it was thought the principle might be applied to thin-cased bombs for use against ships from low altitudes, thereby greatly increasing the chance of a hit. This principle was by no means a new one. Experiments in its use for demolition had been made as early as 1889, but it had been revived just before and during the early years of the war of 1939. Briefly, there were at that time three lines of development of the shaped charge for bombs, the Plastic nose, Disc or Disc-ring, and Hollow charge.

The plastic nose

In this type of bomb the charge was contained in a conical shaped light casing in the nose of the bomb. On impact with any heavy plate the nose flattened, and on detonation cut out a disc of the plate material, driving it like a projectile into the space behind the target plate. This would usually be part of the armour of a ship, and the disc would in this case be propelled through the ship, and, it was hoped, through the bottom. It was essential for success that the first object struck by the bomb was a steel plate at least 1½ inches in thickness ; any impact before this on lightly armoured superstructure would largely destroy the projectile effect. It was estimated that a bomb of 36 inches diameter, weighing some 3,000 lb., would drive a plug of steel right through a capital ship at a velocity of from 4,000 to 5,000 feet per second, provided always that it struck first at least 1½ inches of deck armour.

The disc or disc-ring charge

It was unlikely that a bomb would in every instance find as its first point of impact a plate of the necessary thickness, and quite probable that some light superstructure would be hit first. In this case it was necessary to provide the bomb with its own projectile, which took the form of a steel disc either plain or strengthened by a ring round its edge, in front of the explosive. Without the ring there was the chance that the disc would be shattered into fragments too small to have any driving effect. It was estimated (from small scale experiments) that to defeat a capital ship of the *Tirpitz* class, a bomb would have to have a diameter of 60 inches and a weight of about 7,000 lb. for the disc type, and of 36 inches and a weight of 5,000 lb. for the disc-ring type.

The hollow charge

This form of charge employed the ' Munroe jet ' effect.[2] A hollow portion was left in the nose of the bomb in the form of a truncated cone. Its effect was, in a sense, to focus the energy of detonation on a point opposite the hollow

[1] A.M. File C.S. 13747.

[2] Discovered by Dr. Charles Munroe, 1889.

in the form of a jet. Small scale trials had shown this type to be better than the soft nose, but inferior to the disc or disc-ring form. The advantage to be gained from any of these forms of shaped charge was that of ability to achieve results from low heights, with greater chances of hitting. The orthodox air weapon for the attack of ships was the armour-piercing bomb, but to achieve the necessary striking velocity on which the value of the bomb depended, it was essential to bomb from as great a height as possible, when the problems of accurate aim became greater. In actual fact, however, the choice was by no means as simple as this. With lessened height of release, the angle of the bomb with the vertical became greater ; but there was a limiting angle for the shaped charge to produce its maximum efficiency, and this could not be obtained with very low heights of release. To overcome this difficulty experiments with parachutes were tried but proved a failure. Small scale trials against models of ship plate structure, completed by the end of January 1942, indicated that complete penetration from deck to bottom could be obtained against the most heavily armoured capital ship if hit by a soft-nosed bomb weighing approximately one ton and containing 75 per cent. of explosive. These trials impressed the Ordnance Board, who recommended that trials on a larger scale should be undertaken at Shoeburyness, using an arrangement of armour and other plates of suitable thickness to represent various ship sections.

On 13 March a meeting was held under the Chairmanship of the President of the Ordnance Board to discuss the trials so far concluded, those to be organised at Shoeburyness, and air trials.[1] Lord Cherwell was again present, with representatives of all interested Departments of the Admiralty, War Office, Air Ministry and M.A.P. D.O.R. stated a requirement by the Air Staff for a bomb of this kind ' to bridge the gap between attacks by airborne torpedoes and high altitude A.P. bombs.' Attacks from between 10,000 and 1,500 feet with the shaped charge bomb were visualised. Any risk in attacking a ship from 1,500 feet was to be accepted. One-quarter scale trials were agreed on against model plate arrangements representing *Tirpitz* and H.M.S. *King George V*. The plate structures were to be closed laterally so that the effects of blast might be measured, with an angle of attack of 30°, using the soft-nosed and disc-ring types of bomb. The service design of bomb and fuze and the problem of stowage in aircraft were to be examined by C.S.A.D., D.Arm.D. and M.D.1.

On 28 March a further meeting assembled at Thames House with the Vice-President (Air) of the Ordnance Board in the Chair, to discuss the design of the disc-ring bomb.[2] Representatives from M.D.1 (the designers), D.Arm.D., D.O.R., C.S.A.D., and C.S.R.D., attended.

The requirements which had by this time been drawn up by the Air Staff were given by D.O.R. They were :—

(*a*) The bomb must be capable of being accurately aimed.

(*b*) Dropping heights were to range from 1,500 to 10,000 feet.

(*c*) The bomb must be capable of being dropped safe if possible.

The size of the proposed bomb was then discussed. The original diameter required by M.D.1 to give the necessary perforation and blast was 45 inches. The only aircraft capable of carrying such a bomb was the Lancaster, and then only with the bomb doors sixteen inches open. A reduction of seven

[1] A.M. File C.S. 13747.
[2] M.A.P. File S.B. 36452.

inches would give the bomb the same diameter as the 8,000 lb. H.C. bomb and allow it to be carried in a Halifax, which would accommodate two such bombs, as well as in a Lancaster, which would take one. It was accordingly agreed that bombs of both 45 and 38 inches should be constructed, and the filling was to be R.D.X./T.N.T. Static and ballistic trials were arranged at Shoeburyness, static trials against 'Job 74', the Naval representative plate target, and live drops were arranged. For the initial trials, a simple percussion fuze was to be used, but a more elaborate fuze to operate on water would eventually be required should the bomb finally come into service. The bomb was to be known officially as 'Bomb C.S. type D.R.', C.S. denoting Capital Ship and D.R. disc-ring.

Full scale trials commenced on 14 April, at Shoeburyness with the 45 inch bomb. The total weight of the bomb was 4,890 lb., the weight of R.D.X./T.N.T. being 2,121 lb. The target plates were $\frac{3}{8}$ inch mild steel, and 2 and $3\frac{1}{2}$ inch Nickel Chrome steel, all being inclined back at 15 degrees, in the order: $\frac{3}{8}$ M.S., 2 inch N.C., $\frac{3}{8}$ M.S., $3\frac{1}{2}$ inch N.C., and represented a section through *Tirpitz*, the German battleship, the plates being spaced 8 feet apart. At detonation the target was completely demolished, the $3\frac{1}{2}$ inch N.C. plate having a hole about 5 feet by 5 feet. D.N.C. gave as his opinion that, had the *Tirpitz* been struck by such a bomb, directed towards its magazine, it would have been blown up. In any other direction, damage would have been so great that at least a year would have been required to repair it, should the ship have got back to her base. His report concluded with the words :—

> 'If such a bomb is operationally practicable, it is, in my opinion, the most effective anti-ship weapon yet seen.'

Further full scale trials were completed on 8 May, with a 45 inch bomb, on a modified target.[1] The plate target in this trial consisted of four flat parallel plates, of thickness $\frac{3}{8}$ inch M.S., 2 inch N.C., $\frac{3}{8}$ inch M.S. and 6 inch N.C., spaced 8 feet 6 inches apart. On detonation the 45 inch bomb demolished the target, but the 6 inch plate received superficial damage only, remaining almost in its original position. D.N.C. found as a result that 'the bomb is incapable of penetrating six inch N.C. armour disposed in the structure similar to that of the *Tirpitz*. The dissipation of the forces and fragments on one single 6 inch deck would however do extensive damage to structure and fittings over a large area in the vicinity, and the extent of the damage might well put a ship out of action for several months'. On the same day a 38 inch bomb was fired against a target consisting of plates $\frac{3}{8}$ inch M.S., 2 inch N.C., $\frac{3}{8}$ inch M.S., $3\frac{1}{2}$ inch N.C., but the angle of attack was at 35 degrees. The bomb contained approximately the same weight of explosive as the 45 inch bomb, but had a disc only on the nose, with no ring. In this trial the $3\frac{1}{2}$ inch plate was split and holed: the total area of destruction being about 3 feet by 4 feet.

As a result of these full scale experiments the Ordnance Board gave as their opinion that the C.S. disc or disc-ring bomb 'has great possibilities for the attack of armoured ships. Both the 45 and 38 inch bombs are capable of defeating at a striking angle up to 35 degrees a representative ship target embodying total thickness of approximately 6 inches of armour'. It was noted however that such armour was not representative of the best protection carried by modern enemy ships. They recommended further trials against more representative targets, and the development of a 30 inch bomb.

[1] O.B. Proc. Q. 600.

The trials recommended by the Board were completed with model bombs at Shoeburyness by the middle of 1942. On 22 April two disc ring model bombs were fixed in position against a quarter scale model of deck thickness and disposition thought to exist in the *Tirpitz*. The bombs were quarter scale representations of the proposed C.S. bombs of 45 or 38 inches diameter. An elaborate illustrated report was published by the Ordnance Board and should be consulted for complete details.[1]

The first bomb was a model of the 45 inch disc-ring type and was placed on the superstructure deck, inclined at 15 degrees to the vertical and directed so that the jet would hit the transverse bulkhead at about midway between the middle deck and the inner bottom. Although penetration and blast were less than would be expected from a full scale experiment, the outer bottom was perforated in at least one place, and it was calculated that in the actual ship, at least three main compartments would have been flooded. Cordite placed in the relative position of the *Tirpitz* magazine was completely burnt.

The second bomb, similar to the first, was placed on the superstructure deck of a model section of deck thickness and dispositions in H.M.S. *King George V*, and inclined at 30 degrees to the vertical. Results were similar, penetration was considered adequate but blast disappointing. D.N.C. in his report on these initial trials, concluded that the results were promising and that resulting damage would probably be greater than the models indicated.

Similar trials with models of the 38 inch disc ring and plastic bombs were made on 30 May with similar results. In their summing up of the trials, the Ordnance Board concurred with D.N.C's. remarks on Bombs 1 and 2. They found it difficult to assess the relative merits of disc-ring and plastic bombs in trials 3 and 4 : on the whole evidence favoured the plastic type which with about half the weight of the disc-ring type, did a similar amount of damage.

While these damage trials had been proceeding under the supervision of the Ordnance Board, installation and ballistic trials were completed at Boscombe Down and Porton, by A. & A.E.E.[2] For installation tests a Lancaster had been modified by the fitting of larger bomb doors. The report was favourable, fuzing and hoisting were satisfactory, and a bomb dropped from 4,000 feet was stable in flight.

By August 1942 it was evident that although both disc-ring and plastic nosed bombs were efficient weapons, provided they could be placed in the correct position in the ship, and at the right angle of altitude—*i.e.*, at 35 degrees or less to the vertical—it was still difficult to decide which was the more efficient. The Air Staff accordingly decided that a soft (plastic) nosed bomb should be developed, so that the relative merits of the two types could be decided by operational use when the opportunity occurred.[3]

So far little doubt about the value of the C.S. bomb of one type or another seemed to have been felt. By September 1942, however, it was becoming clear that severe limitations in the use of the bomb must arise.[4] By that date, model experiments with both 45, 38 and 30 inch bombs had shown that to defeat a total of 8 inches of armour, the striking angle of the bomb must not

[1] O.B. Proc. Q. 622, Appendices A, B and C.
[2] M.A.P. File S.B. 36452.
[3] O.B. Proc. Q. 670.
[4] O.B. Proc. Q. 729.

be more than 15 degrees to the vertical. To obtain such an angle, the bomb would have to be released from a height of at least 20,000 feet unless it were fitted with some form of drogue, in either case accurate aim would be extremely difficult. To defeat this amount of armour, it was calculated that a 2,000 lb. A.P. bomb from 10,000 feet would be sufficient, and thus it appeared that the C.S. bomb compared unfavourably with the A.P. Even should the performance of the C.S. bomb be improved so that effective damage from lower heights could be obtained, the chance of a hit, would still be in favour of the A.P. bomb because, four, six or even seven of these could be carried in the space occupied by one or possibly two C.S. bombs.

These considerations of the Ordnance Board were sharply criticised by Lord Cherwell who had sponsored the C.S. bomb from the beginning.[1] He argued that they took no account of the velocity with which the C.S. bomb struck the target, and that in any case there was nothing against the use of a drogue which would give the necessary striking angle of 15 degrees from as low a height as 1,500 feet. He regarded any argument that the employment of drogues decreased bombing accuracy as fallacious, and maintained that the use of the C.S. bomb from low heights—for instance on conditions of bad visibility—was its greatest asset. Finally he pointed out that the A.P. bomb makes a small hole in superstructure or armour, while the C.S. bomb destroys a great part, wrecking range finding and other equipment on at least half the ship, and that a near miss with an A.P. bomb is valueless, while a near miss with a C.S. bomb is probably damaging. The Ordnance Board while agreeing with some of these arguments, pointed out that these figures had been approximate, gave more accurate ones, and maintained that their original contention remained substantially unaltered. Making all allowances for the increased damage expected from the C.S. bomb, they showed that, by virtue of the increased load of A.P. bombs, the relative chance of damage from either direct hit or near miss was 2·7 to 1 in the Lancaster and 1·8 to 1 in the Halifax, in favour of the A.P. type.

The tactical use of the bomb from low altitudes was very unfavourable to success in the opinion of the squadron commander, and some of the pilots, of the bomber squadron earmarked to use the bomb. They had by then received instruction in the use of the Low Level Bombsight for aiming the C.S. bomb and had witnessed the most recent trials in July 1942. This opinion as to the use of the bomb was supported by the C.-in-C. Bomber Command, who was of the firm opinion that dropping from low altitudes was not a practical war operation and this was confirmed by the Air Staff in October when A.C.A.S.(T) informed the Controller of Research and Development (M.A.P.) that the official requirement for minimum height of release was 5,000 feet.[2]

By November 1942, the design of the 38 inch bomb recommended by the Ordnance Board was completed by M.D.1 and the manufacture of bombs for the operational tests suggested by the Air Staff had begun.[3] Work on the design of the 30 inch bomb had been commenced by C.E.A.D. and was the subject of a discussion at a meeting of the Ordnance Board, on 22 December 1942.[4] Lord Cherwell and explosive experts of the Research Department were

[1] O.B. Proc. Q. 777.
[2] A.M. File C.S. 13747.
[3] O.B. Proc. Q. 847.
[4] O.B. Proc. Q. 891.

present, as well as Air Ministry and Naval representatives. It was agreed that the bomb should be fitted with a parachute (or drogue) and its ballistics calculated so that sighting figures might be produced. The filling was to be Torpex, and angles of impact up to 35 degrees were to be used in tests. (It was subsequently found that no Torpex was available for trial, and the filling was changed to RDX/TNT). Before the design of a suitable parachute could be commenced, a suitable terminal velocity figure was required. In January 1943, it was agreed that the T.V. should be adjusted so that the striking angle should not exceed approximately 40 degrees when the bomb was dropped from a minimum height of 500 feet at a maximum speed of 250 m.p.h. The design of the parachute was then undertaken by D.R.A.E.

The plate trials of the 30 inch bomb were completed at Shoeburyness on 27 March[1] against a series of plates, set at an angle of 15 degrees in the following order :—

4 inch M.S.
3 inch N.C.
⅜ inch M.S.
3½ inch N.C.
1 inch M.S.
1 inch M.S.
1 inch M.S.
1 inch M.S.

They showed that the bomb was just able to defeat this target without the additional power obtained from striking velocity, which was of course absent in the trials. As a result D.Arm.D. ordered a number of 30 inch bombs for operational use.

There were now three types of C.S. bomb, 45 inch, 38 inch and 30 inch, of which small quantities had been manufactured for operational trial. In addition to these, C.S.A.R. had proposed a 'follow-through' bomb—that is to say a light case hollow-charge bomb which would blow a hole in armour or concrete, with, behind it, a heavy projectile which by its momentum would follow through the opening made by the initiating nose.[2] As proposals for a 4,000 lb. A.P. bomb, and for the redesign of the existing 2,000 lb. A.P. bomb were also under discussion during the first half of 1943, it seemed to the Ordnance Board that a meeting at which representatives of the Board, Air Ministry, Admiralty and War Office could discuss these various projects for the attack of capital ships was advisable.[3]

The meeting was held at M.A.P. on 24 June 1943 with the Vice-President (Air) of the Board in the Chair. The view of the Air Staff on the C.S. bomb as then designed was given first of all by D.O.R.'s representative who stressed the great disadvantage of all types of existing C.S. bombs. The 45 inch original bomb had required considerable modification to the Lancaster. The 38 and 30 inch bombs could be carried without modification to the aircraft but only singly. The Air Staff considered that while improvements in the performance of the 30 inch bomb would be acceptable, what was really required was a bomb which could be carried in satisfactory numbers. The ideal sought was an 18 inch bomb capable of dealing with the heaviest enemy capital ship.

[1] O.B. Proc. Q. 1199.
[2] O.B. Proc. Q. 1188.
[3] O.B. Proc. Q. 1355.

After discussion the meeting agreed that there was then no hope of meeting this requirement. The same arguments were applied to the proposed 4,000 lb. A.P. bomb. No aircraft could carry more than one, and the chance of a hit with one bomb was small. In any case D.Arm.D. could not promise the production of such a bomb within two years. The meeting agreed that there was no immediate requirement for such a bomb. The ' follow through ' bomb was then discussed and, because of its complication and the fact that it too could only be carried singly, the meeting decided that there was no requirement for it. The only positive decision made was to increase the effectiveness of the 2,000 lb. A.P. bomb by an increase in explosive capacity.

Finally it was agreed that none of the bombs discussed could be used effectively for the attack of concrete submarine pens, a target which assumed greater and greater importance as the war went on. It was not until December 1943 that proposals from the Admiralty for the design of a special rocket assisted concrete piercing bomb were received by D.Arm.D. and passed to the Ordnance Board for consideration. These led to the development of the 4,500 lb. ' Disney ' bomb, used by the 8th American Air Force during the latter months of the war.

At a meeting held by the Secretary of State for Air on 19 July 1943, to consider the ' development and production of items of Scientific equipment ', A.C.A.S. Ops., ruled that there was no further operational requirement for the C.S. bomb, and no further orders were to be placed. In all fifty of each size had been made, although not all had been filled with high explosive. By the middle of 1944 there remained only six 45 inch, twenty-four 38 inch and forty-five 30 inch with odd numbers of components, these were later reduced to scrap.

No C.S. bombs were used in serious bomber operations. A few 38 inch bombs were dropped on ships in Gdynia harbour in 1942 with unknown results. There is however no reason to doubt the opinion of the Director of Naval Construction, quoted earlier, that the bomb was the most effective anti-ship weapon yet seen. D.N.C. did, however, qualify his statement with the words ' if it is operationally practicable,' which in fact was not the case. To obtain a direct hit with single bombs is no easy task, and the bomb demanded not only a direct hit, but one in the right place and in the right attitude.

CHAPTER 10

THE MEDIUM CAPACITY SERIES BOMBS

On 6 December 1940, a somewhat belated meeting under the chairmanship of the Deputy Chief of Air Staff was held to decide whether British G.P. bombs were good enough.[1] Intelligence information appeared to show that British bombing had been to some extent ineffective, that many bombs did not detonate, and that the damage by those which did, particularly to electricity, gas and water mains, was not so great as that caused by German bombs in this country. One obvious reason for the final statement was that while the charge/weight ratio of G.P. bombs was only some 27 per cent. that of the corresponding enemy bomb was in the neighbourhood of 50 per cent.

The general conclusions of the meeting were :—

(*a*) That 500 lb. bombs were generally more effective for a given tonnage than 250 lb. bombs on most targets.

(*b*) That the very high charge weight ratio of blast (H.C.) bombs has only a limited application.

(*c*) That investigation should commence at once into the design of a bomb to replace the 500 lb. G.P. bomb : the new bomb was to be roughly of German design, with parallel sides and a relatively heavy nose : the charge weight/ratio was to be raised, without undue sacrifice of case strength.

The meeting went on to discuss suitable lengths of delay, the minutes recording that there was ' considerable discussion as to what represents the ideal delay '. It may be considered that a firm opinion on such an important point ought to have been formed some time before the date of this meeting which took place a year and three months after the commencement of the war.

As a result of these findings, D.O.R. prepared a draft requirement for a new bomb. It was to resemble the German S.C.[2] bomb which had been found particularly effective against certain targets, and was to be carried in any position designed for the 500 lb. G.P. bomb. The charge/weight ratio was not to be less than 40 per cent. and the body might be cylindrical provided it had reasonably good ballistics and would stand up to impact stresses. The bomb must be able to penetrate modern multi-storied buildings, and metalled roads, coming to rest in a state to give complete detonation from 2,000 feet and above. Fuzing was to be limited in the first place to N.D.T. and 0·12 second tail fuzing only.[3] The filling was to be the best obtainable, preferably R.D.X. and the usual safety requirements were added. The bombs must be of a construction suitable for mass production and have reasonably high ballistic qualities.

[1] Vice Chief of Air Staff, Director of Armament Production, Director of Armament Development, Assistant Chief of Air Staff (Technical), and representatives of the Directorate of Plans, Directorate of Operational Requirements, and the Ministry of Home Security attended. The Ministry of Home Security was represented by Professor Bernal. A.M. File C.S. 7557.

[2] Spring Cylindrisch.

[3] Non-delay tail : estimated at about 1/400 secs.

The 500 lb. bomb

These requirements were put to the Ordnance Board on 30 December 1940, and the Chief Superintendent of Design, at once started on the design of a bomb case. A sketch design was produced by the end of January, and the new bomb was given the name 'Bomb H.E. 500 lb. M.C. (medium capacity)'. The method by which the new bomb was to be manufactured was at first the subject of a great deal of argument and discussion. Four methods were available: the bomb could be forged in one piece: the cylindrical body could be drawn, and a heavy nose welded to it: the body could be made of welded sheet, or a process known as centrifugal casting could be employed. A filling of Amatol had to be accepted at the beginning as no R.D.X. was available.

Eventually the proposed methods were reduced to two: forging, which would be very slow, and welded sheet steel, the most productive method should it prove strong enough. It is interesting to note that the corresponding German bombs had originally been made in this way, but later forged bombs in one piece had appeared. By February 1941, D.Arm.D. had raised a technical requisition for ten bombs from each of five manufacturing firms. These were to be manufactured by one or other of the methods outlined above, and were to have comparative tests against a hard target. The contractors were instructed to conform to the outline and wall thickness scheme in C.S.D.'s sketch design, but otherwise were to employ their own method of construction. Later, contractors were asked to produce ten bombs from drawn tube.

Eight inert filled bombs were tested at A. & A.E.E. on 4 April 1941.[1] These were of sheet plate welded longitudinally, the nose being in turn welded to the resulting cylinder. Trials against the Porton hard target from 2,000 feet were fairly satisfactory, but from 4,000 and 6,000 feet the bombs suffered severe damage. Five of these bombs were reconditioned and dropped on the Porton hard target on 21 April 1941, again with unsatisfactory results. It was clear that bombs of this construction were unsuitable and further work by that firm was cancelled.

On 26 and 27 May 1941, bombs were dropped at A. & A.E.E. for impact trials. Two types were tried: one with a solid and one with a plugged nose. In trials from 2,000 feet all withstood impact satisfactorily. The choice had therefore to be made by consideration of the ease of manufacture. While the solid drawn method was probably the more satisfactory, the pressed steel method lent itself more readily to rapid bulk manufacture. After discussion with the Ordnance Board, D.Arm.D. therefore decided in June 1941 to place a development order for one thousand bombs of the latter type.

So far the design of bodies only has been discussed, but concurrent arrangements were made by D.Arm.D. for the manufacture of tail units, similar to those used in the G.P. bomb Mark IV and designed by C.S.D. The plugged nose had shown itself in trial to be as strong on impact as the solid nose, and the new bomb was therefore designed to have a recessed nose for an exploder system, which resembled again that of the G.P. bomb.[2]

In August 1941, it was evident that the progress of this contract for bomb bodies manufactured in one piece would be slow, and the urgency for the bomb to replace the G.P. type—whose shortcomings were becoming more and more

[1] A.M. File C.S. 7557.
[2] M.A.P. File S.B. 13798.

evident—was already great. Accordingly it was agreed that further experiments with welded construction must go forward. By the end of October 1941, various trials of both types of bomb, with inert and H.E. fillings, had been completed. Inert filled bombs, both one-piece and welded, had been dropped on the hard target at Porton, and both types had given satisfactory results. The solid wall type had also been dropped on the special target at Braid Fell, again satisfactorily. On 25 October, nine H.E. filled bombs were tested by A. & A.E.E. at Ashley Walk.

In the live trials various types of fuzing were tested: three bombs were dropped with nose instantaneous, three with tail instantaneous, and three with tail delay of 0·12 second. All were satisfactory from 4,000 and 2,000 feet. These bombs were filled 50/50 amatol. The original intention had been to use R.D.X./T.N.T., but supplies of R.D.X. were still very limited. The bomb was, however, placed first on the priority list for R.D.X. filling. Trials with this filling were completed in November 1941, at Crichel Down and Ashley Walk: three bombs were dropped on chalk and three on wet clay, from heights similar to those used for the amatol filled bombs. A comparison of the craters left no doubt that the R.D.X. bombs were much superior to those filled with amatol. Arrangements were therefore made for all bombs under manufacture, still unfilled, to have an R.D.X./T.N.T. filling, the number being some four hundred. In the same month the 'solid wall' type bomb was approved for service use, the first four hundred were to be equally allocated to Bomber Command and Coastal Command for attacks on enemy merchant shipping.[1]

In October 1941, a report was received from the Inspector-General of the R.A.F. on a visit to Eritrea emphasising the ineffectiveness of G.P. bombs, an opinion confirmed in a report from the Middle East on the examination of bomb damage in Syria.[2]

These reports made it evident that an immediate replacement for these bombs was urgent and that no delay in the production of the M.C. bomb could be tolerated. So far only solid-drawn bodies had been tested and approved, but various firms were engaged with development orders for welded bombs, as yet untried. The only source available of the former type was the Chesterfield Tube Co., whose maximum output could not exceed 1,000 per month without lengthy and extensive additions to their plant. Trials of the welded bombs on the hard target at Braid Fell had been arranged in December 1941, but production delays through war damage had arisen and there seemed little prospect of the trials commencing before 1942.

The supply position at the end of November 1941 was that only the original development order of 1,000 solid drawn bombs was in hand, there was no planned production, but D.Arm.P. was investigating the possibility of a monthly output of 20,000 bombs—which would include 3,000 of the solid drawn type—at the expense of 500 lb. and 1,000 lb. G.P. production. On 4 December 1941, a meeting was held by D.B. Ops. at Air Ministry to discuss the production position, and it was decided to go ahead with all possible production of both the solid drawn and welded bombs with every effort being made to produce as many of the former as possible until the latter had been proved in the Braid Fell trials. If necessary this increased production of M.C. bombs was to be effected at the expense of the 500 lb. S.A.P. type.

[1] A.M. File C.S. 7557.
[2] A.C.A.S.(T) 4320, 25 October 1941 and D.B. Ops. 2126, 23 November 1941.

By February 1942, however, it was apparent that very little progress was being made, for in that month a forecast of empty 500 lb. M.C. bomb production for 1942 made by D.Arm.P. showed the following :—

May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
150	500	1,000	2,000	3,000	4,000	5,000	6,000

These figures represented only 0·5 per cent., 4·3 per cent. and 8·5 per cent. of the total requirements for 500 lb. bombs—G.P. or M.C.—for the 2nd, 3rd and 4th quarters of that year. Shortly after this estimate was given an unsuccessful effort was made to have production increased by manufacture in the U.S.A. or Canada. All capacity in those countries was needed for bombs of standard American design, but there was a possibility that a similar American bomb—the A.N.M.43—could be supplied empty to this country, and the technical aspects of filling and carriage on British aircraft were being considered by D.Arm.D.

So serious was the prospective supply position that on 25 March 1942 the Chief of the Air Staff took the matter up personally with D.B. Ops, whom he instructed to examine the production of M.C. bombs on the highest priority. The same day D.B. Ops. consulted D.O.R. and D.Arm.P., the latter providing the following information.

Anticipated production had risen to these figures :—

May	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
150	600	1,500	3,000	5,000	6,000	8,000	10,000

cumulative, and this was the maximum possible with the existing methods of production. Any material increase could only be obtained by setting up new factory and plant at a cost of about £165,000 and with a delay of some 18 months. As an alternative, D.Arm.P. suggested that a cast steel bomb could be made. The disadvantages would be a possible reduction in strength and a certain reduction in charge/weight ratio as the case would have to be increased in thickness from 0·3 inch to 0·4 or 0·5 inch. The resulting charge/weight ratio would be in the regions of 43 per cent. - 46 per cent. On the other hand, the factories producing G.P. bombs could readily turn over to this production with very little loss of time, or capital expenditure.

So attractive did this proposal seem that it was agreed D.Arm.P. should immediately inform D.Arm.D., and that together they should approach the Controller of Research and Development for authority to get out production plans.

Meanwhile important trials, both by static detonation and air dropping at Crichel Down, had been taking place in order to ascertain the best filling for M.C. bombs. The recommendation made by the Static Detonation Committee on these trials was as follows :—' After reviewing the results on trials on 500 lb. M.C. bombs filled (*a*) R.D.X./T.N.T. 60/40, (*b*) Amatex, *i.e.*, R.D.X./T.N.T. 60/40—15 parts ; Amatol 60/40-85 parts, (*c*) Amatol 50/50, the Committee concluded that for general demolition purposes against buildings, Amatex filling (*b*) is as efficient as R.D.X./T.N.T. 60/40 for 500 lb. M.C. bombs, and should be used to conserve R.D.X.' This recommendation was subsequently approved by D.O.R.

No time was lost in the development of the cast steel bomb, and, by 2 April 1942, twelve of this type had been produced and were awaiting hard target trials. This method of increasing production sounded so attractive to the

Air Staff that V.C.A.S. was inclined to give M.A.P. *carte-blanche* to go into production forthwith, with only factory hammer tests, although it was realised that the strength of the bomb would possibly be much less than that of the solid drawn type. This proposal was strongly resisted by D.O.R., who insisted on full scale dropping trials at Braid Fell before acceptance, and sharply deprecated ' a policy which gives the Production Department of M.A.P. a blank cheque to produce quantity without regard to quality. On the other hand A.C.A.S.(T) wished to avoid at all cost a long series of trials which would delay the introduction of the new bomb indefinitely. C.R.D. agreed with D.O.R. that hammer tests could not be regarded as a safe substitute for dropping tests against a resistant target, and undertook to arrange speedy trials before recommending acceptance of the new design.

On 31 May 1942 the first cast M.C. bombs were tested by A. & A.E.E. at Ashley Walk and Porton. At the former range bombs were released from 100 ft. at 200 m.p.h. against concrete wall targets whilst at Porton they were dropped from 2,000 feet at 200 m.p.h. against the hard target. The results showed that although the bombs were capable of resisting direct impact against concrete structures at 300 feet per second they would not stand side impact at that velocity, and were therefore only suitable for instantaneous fuzing.

In view of the extreme urgency of increasing production D.Arm.D. agreed to accepting the 0·4 inch thickness bomb providing it withstood the test conditions imposed by him, and that such manufacture should only be undertaken by firms specified by D.Arm.P. He also recommended the manufacture of 0·5 inch case bombs by a few selected firms, subject to test. A comparison of the two types of bomb showed that the 0·4 inch would weigh 470 lb. with a charge/weight of 46 per cent., the 0·5 inch being 490 lb. and 43 per cent.[1]

In July 1942, trials on the Braid Fell target with fabricated (welded) bombs were completed. Bombs were dropped from 70, 2,000, 8,000 and 10,000 feet. Those released from 70 feet showed no damage to welds, but those from greater heights which struck girders or stanchions were damaged, some very extensively. This conclusion was confirmed by further trials on production bombs in September. From heights above 7,000 feet the bombs were liable to fracture on encounter with a resistant target. D.Arm.P. was requested to examine the welding processes employed by the manufacturing firms and make every effort to improve them. He pointed out that up-to-date hand welding had been necessary as no automatic plant was available—nor would it become available before April 1943. Further, that not only trade experts of the Welding Institute, but also the Ministry of Supply Advisory Service on Welding, were giving thought to welding improvement. Meanwhile as the urgency for bombs was greater than ever, the only possible solution was to reserve the solid drawn bombs—of which very limited supplies were available—for special targets, and to use the welded, and later if approved, the cast bomb, for less resistant targets.

Investigation into the improvement of welding methods continued throughout 1943 but little progress was made. In January a series of tests was made at A.I.D. Test House, Harefield by a representative of the Ministry of Supply Advisory Service on Welding. Samples of welds by various firms were tested by breaking in a vice by hammer blows. Samples from three firms were well below the standard needed.

[1] A.M. File C.S. 7557.

In February a meeting was held at M.A.P. under the chairmanship of D.Arm.P. to ' discuss defects and variations in welding which are causing an excessive percentage of failures during tests and operations of 500 lb. M.C. bombs and to make decisions to effect improvement '. Apart from representatives of D.Arm.D., D.Arm.P., and the Ministry of Supply, Works Managers and representatives of thirteen contracting firms were in attendance. After a discussion on technical failures and methods, the contracting firms formed themselves into a Committee and all contractors agreed to co-operate, to exchange information, and to take every possible action to improve welding practice.

Unfortunately in spite of all efforts it was found impossible to produce by this method bombs capable of withstanding the same impact forces as forged bombs, or even the cast steel bombs. As late as August 1943, extensive failures during tests on the Braid Fell concrete target were still encountered. Mr. Wilson Bennet, the chairman of the Contractors' Committee referred to above, was asked to visit Braid Fell to examine the bombs.[1] At an informal meeting with D.Arm.P. before the visit, Mr. Bennet expressed the opinion that it was impracticable to contemplate that bombs of fabricated construction could be produced with existing facilities '.

It may be of assistance at this stage to tabulate the various marks of 500 lb. bombs in existence or under development at the end of 1942 :—

Mark I. The welded or so called ' fabricated ' bomb ; sides made of rolled steel plate to which the ends were welded. This bomb was strong enough from low heights but liable to fracture from high altitudes against strong targets.

Mark II. Drawn from a solid steel block or forged from a billet ; it was the most reliable bomb, but manufacturing was slow and somewhat extravagant in steel. Owing to the superiority of this type over all others the Air Staff had in mind the segregation of Mark II bombs for selected targets.

Mark III. Made of cast steel—the simplest and most productive of all methods of manufacture—but up till then not approved for service use as its ability to withstand impact on strong targets had not been proved.

Mark IV. Also cast-steel, produced in October 1942, as a special version suitable for quick production and as a result of D.Arm.P's. investigations into many schemes to increase production of M.C. bombs. This bomb was five inches shorter than the standard M.C. type, weighed 440 lb. with a charge/weight ratio of 40 per cent. and was satisfactory in Braid Fell target trials in November 1942.[2]

Despite its smaller size and lower charge/weight ratio ; its capabilities and ease of production warranted its approval for service use in December 1942.

The 500 lb. ' Cast ' bombs, Marks III and IV

Between December 1942 and April 1943, Mark III bombs from three different firms were tested at Braid Fell.[3] These trials were reasonably satisfactory and D.Arm.D. recommended the approval of the Mark for Service issue, subject to

[1] M.A.P. File S.B. 13798.
[2] A.M. File C.S. 7557.
[3] M.A.P. File S.B. 25455.

satisfactory detonation trials. On 7 March 1943 a trial of M.C. bombs against vehicles at Crichel Down bombing range was completed, and was very successful. Mark III bombs were tried (among others) and as a result A.C.A.S. (T.R.) gave unqualified approval for their introduction.[1]

One other point in connection with the introduction of the cast bomb—and another Mark—deserves mention, particularly as it illustrated the difficulties in the production of bombs by various firms inexperienced in such manufacture, as did the serious difficulties met—and never completely solved—in the welding of the so-called ' fabricated ' bomb.

It was found that some six thousand bombs, from various manufacturers, had their centre of gravity outside the limit imposed in the specification. To avoid the extravagance of scrapping this valuable material D.Arm.D. agreed to accept these bombs providing they were segregated for use with long tail units and by the allotment of a new Mark number. They were accordingly designated Mark V.[2]

In August 1943, following an arrangement with the United States that certain bombs under production could be fitted with supplementary American lugs, steps were taken to include all Marks of 500 lb. M.C. bomb.[3] This entailed the allotment of new Mark numbers to the modified bombs and Marks I to IV became, when fitted with American suspension lugs, Marks VI to IX respectively.[4]

Bomber Command trials with 500 lb. M.C. bombs

It is inevitable that all types of bomb, but particularly those used in large numbers, should from time to time fall under the suspicion of their users. Reports and stories of bomb failures have always been rife, and are, in war time, extremely difficult either to confirm or refute. The 500 lb. M.C. bomb was no exception and in July 1943, the C.-in-C. Bomber Command wrote to the Air Ministry (D.O.R.) for confirmation that the cast bomb could be used against all targets and from all operational heights, with delay fuzing. The Command questioned the value of impact trials on the Braid Fell concrete target on the ground that the inert filling used did not give a fair indication of the ability of a bomb filled with H.E. to withstand impact before detonation.[5]

About the same time reports were received by Air Ministry throwing some doubt on the reliability of the M.C. bomb.[6] Bombs dropped accidentally over Switzerland were reported to have failed : in July a report from the Political Intelligence Department of the Foreign Office suggested that in bombing raids over Belgium, 30 to 40 per cent. of bombs failed to detonate.[7]

These criticisms of the bomb led to an exposition by D.Arm.D. describing exactly what the bomb was capable of achieving, and its known limitations, all of which information had been readily available to Operational Commands. The bomb was primarily a substitute for the older G.P. bomb from which it differed, essentially, only in its increased H.E. capacity. It was not stronger than the G.P. bomb, and was never intended for severe impact, particularly

[1] M.A.P. File S.B. 35485.
[2] M.A.P. File S.B. 44250.
[3] Others were the 1,000 lb. and 4,000 lb. M.C. and the 600 lb. A.S. bombs.
[4] M.A.P. File S.B. 35455/2.
[5] B.C. File BC/S/28522.
[6] M.A.P. File S.B. 51178.
[7] P.I.D. (H.S.) 539, 19 July 1943.

side impact, on resistant structures.[1] As has been already described, the high demand and production difficulties made it necessary to resort to welding and casting methods, with a consequent diminution of strength. D.Arm.D. pointed out that neither the corresponding American nor German bombs were better able to withstand severe impact.

His conclusions by way of reply to Bomber Command were, that welded or cast bombs could be relied on against resistant targets (modern multi-storied buildings, factories and power houses) with instantaneous fuzes or at the most 0·025 seconds delay, from any operational height. Against less resistant targets (roads, dwelling houses and older types of multi-storied buildings) any form of delay fuzing would be satisfactory. The same principles applied to low level attack with fast aircraft : with a striking velocity of 400 feet per second or more, impact against resistant targets would probably destroy the bomb before detonation if delays were used.

For longer delays against resistant targets, the forged bomb must be used, but even that bomb was liable to failure on severe side impact. For low height high speed attack against heavy machinery or similar targets, the M.C. bomb was unsuitable, and that the S.A.P. was the correct weapon. Finally he pointed out that the type of H.E. substitute filling was unlikely to prejudice trial results.

D.O.R. in replying to the C.-in-C. Bomber Command, suggested trials arranged by the Command, using both M.C. and G.P. bombs, and both inert and H.E. fillings—the latter with no exploder or detonator, so that difference in behaviour on impact could be observed.

These trials were organised by Bomber Command ; their intention was stated to be :—

> ' To drop a number of 500 lb. G.P. and M.C. and 1,000 lb. M.C. bombs from operational heights against the Braid Fell building target, to register hits on various parts of the target and to obtain evidence of their performance.'[2]

Bombs were to be selected from various Station bomb stores, M.C. bombs manufactured by seventeen different contractors were to be chosen, of forged, welded and cast construction.

The trials commenced in October 1943, and were completed by April 1944. They had by then included low altitude attacks against a concrete wall at Ashley Walk. Reports on the progress of the trials were made from time to time ; it is sufficient to give an analysis of the general conclusions regarding 500 lb. bombs.[3] These were :—

(*a*) The medium capacity bomb, whether forged, cast or ' fabricated ', was sufficiently strong to withstand direct impacts on all normal building targets.

(*b*) For ' girder ' targets—that is those containing heavy steel girders in their construction—only the Mark II (forged) bomb was satisfactory.

(*c*) The forged type was definitely stronger than the cast type, and strong enough against any target when fuzed with delay action, except where penetration into more than three feet of concrete, or the equivalent thickness of armour plate, was required.

[1] M.A.P. File S.B. 51264.
[2] M.A.P. File S.B. 51178.
[3] O.B. Proc. 27309.

(*d*) The Mark III (standard) cast bomb was strong enough for normal impacts with any fuzing provided no girders were encountered. The Mark IV cast bomb was satisfactory on all targets when given not more than 1/10 sec. delay, and 70 per cent. may be expected to withstand similar targets, with longer delay.

(*e*) The Mark I (' fabricated ') bomb was the weakest of all, and should only be given instantaneous fuzing.

(*f*) Premature detonation was liable to occur with delay fuzed bombs, having an exploder system in the nose.

These conclusions contained little new information : the most valuable contribution they made to the development of the bomb, was the discovery—which was however also predictable—that for delay fuzed bombs, nose exploder systems should be omitted.[1] A design of forged bomb later assigned Mark X with a solid nose was therefore evolved, and production commenced at the beginning of 1944. It was quite natural that the immediate outcome of the trials should be a repetition of the demand by Bomber Command for more and more forged bombs. But the Tactical Air Force had also a strong claim, and Bomber Command had to be content with an allocation of 50 per cent. of the output of Mark II bombs.[2] This allocation of only half the output was not so serious as might be imagined, for, as the figures supplied by the Ministry of Home Security showed, the proportion of steel and concrete multi-storied buildings in Germany was remarkably small—less than 1 per cent. of all buildings in the country. This meant that the probability of a hit on such a building in a densely built-up area was less than 0·2 per cent., thus the proportion of M.C. bombs fuzed long delay which might be expected to fail was relatively small.[3]

The 500 lb. M.C. bomb tail

The rather complicated story of the development of the 500 lb. M.C. bomb has so far been confined to the body structure. In conformance with a principle long established, this was provided with a clip on tail. The design for the new tail was produced by C.S.D., and production of the part was undertaken by a civilian contractor, for a small quantity for development purposes.[4]

By June 1941, production of the 500 lb. M.C. bomb had commenced, and a production order for the tail was placed with Messrs. Fisher Ludlow, who were already the contractors for the G.P. bomb tail, a number of whose components were used in the M.C.[5] The design was recommended for approval by the Ordnance Board in the following month.[6] By November 1941, dropping trials had shown the bomb to be quite stable, and in this month its acceptance for service use was recommended by D.Arm.D. None but very minor modifications were made to the original tail, which received the service title of No. 25 Mark IA and which continued to be used in the majority of 500 lb. M.C. bombs throughout the war.

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[1] O.B. Proc. 27234.
[2] A.M. File C.S. 473/D.Ops.Tac.
[3] M.A.P. File S.B. 51264.
[4] D.D.(L) 12073.
[5] M.A.P. File S.B. 13798.
[6] O.B. Proc. 13192.

Towards the end of 1941 however, the need arose for the carriage of M.C. bombs in Mosquito aircraft, and the space available did not allow the orthodox tail to be fitted. A short drum type tail was specially designed for this aircraft, and a series of trials made at Orfordness to test its ballistics. These trials were combined with ballistic trials of the bomb with a standard tail, and showed that when fitted it had good ballistic consistency with a terminal velocity of 1,460 feet per second. The effect of fitting the special drum tail was to reduce the terminal velocity by 70 feet per second and to increase the ballistic errors in range by 70 feet. This shortened tail was given the designating Number, 28.[1]

Bombs with short tails were in fact very near the limit of stability, and the A.O.C.-in-C., A.E.A.F. reported to the Air Ministry in June 1944 that this instability was the probable cause of bomb failures. This instability was most noticeable in bombs carried externally on fighter-bombers: and was ascribed to some extent to weakness in structure. Accordingly a stronger type of tail was designed for external use in fighter-bombers, and numbered 77.[2]

The 500 lb. M.C. bomb, H.E. filling

The original requirement for the bomb had included a H.E. filling to give maximum possible blast, consistent with safety in handling and carriage. R.D.X. was obviously the best choice but was not readily available in 1941 in large quantities. In April of that year D.Arm.D. agreed to an Amatol filling until supplies of R.D.X. became more generous, and asked the Ordnance Board to arrange with C.S.D. for the filling of experimental bombs with 50/50 Amatol and 60/40 R.D.X./T.N.T. for comparative trials. Later 60/40 and 80/20 Amatols were added as alternatives. Meanwhile the bomb was placed as 'first priority' for R.D.X./T.N.T. filling, but since Amatol fillings gave satisfactory results in dropping and static trials, the standard filling was decided at 50/50 Amatol.[3]

Trials by A. and A.E.E. with R.D.X./T.N.T. filling in November 1941, showed that this was definitely superior to Amatol, and arrangements were at once made with the Ministry of Supply to fill all empty production bombs—some four hundred—with R.D.X./T.N.T.[4] The A. and A.E.E. results were only partially confirmed by a series of static trials in December 1941 by the Research Department, Woolwich, and further trials were recommended.[5] The A. and A.E.E. conclusions were however amply confirmed by trials at Gretna where R.D.X./T.N.T. filled bombs were detonated in disused explosives factory buildings, and gave 30 per cent. better results, in general structural damage, than those filled with Amatol.[6]

A further series of static trials was undertaken by the Static Detonation Committee in June 1942, when R.D.X./T.N.T. 60/40, Amatex 15/85,[7] and Amatol 50/50 were compared, the Committee concluded that 'for general demolition purposes against buildings, Amatex filling is as efficient as R.D.X./T.N.T. 60/40 for 500 lb. M.C. bombs, and should be used to conserve R.D.X.'

[1] O.R.S. Reports B.T., 4 November 1941, B.T., 12 July 1941, B.T., 19 October 1942.
[2] A.M. File C.M.S. 577.
[3] O.B. Procs. 1175, 12552, 14241 and 14902.
[4] A. and A.E.E. Report A.T.O. G.35, 29 November 1941, and M.A.P. File S.B. 13798.
[5] R.A.C. 2453/41 and O.B. Proc. 14241.
[6] M.A.P. File S.B. 34635 and O.B. Report 2/39 Proc. No. 1959.
[7] M.A.P. File. Amatex is a mixture of R.D.X./T.N.T. and Amatol: in this case the mixture consisted of 15 parts of the former and 85 of the latter.

Unfortunately the production of 500 lb. M.C. bombs had then begun to reach figures beyond the capacity of R.D.X. available, particularly as both the 8,000 lb. H.C. and the 1,000 lb. M.C. bombs demanded this filling. In January 1943, eight thousand 500 lb. M.C. bombs only could be filled with Amatex monthly.[1]

In September 1943 D.Arm.D. asked for trials with 500 lb. M.C. bombs filled Torpex. These were completed by A. and A.E.E. in November and showed the superiority of a Torpex filling over either R.D.X./T.N.T. or Amatol.[2] Later Minol was used and eventually became the standard filling.

Three features in the development of the 500 lb. M.C. bomb are of special historical interest :—

(*a*) Its design was based not on pre-war thought and experiment, but on observations of the results achieved by enemy bombs. It thus became a substitute for the standard pre-war British Bomb—the General Purpose Bomb—almost at the outset of war, and certainly at the outset of H.E. bombing of enemy and enemy-occupied territory on a big scale.

(*b*) Its immense popularity, and the constant cry for more and more bombs by Bomber Command, and later by overseas Air Forces, placed too heavy a strain on the productive capacity of the country, with a corresponding deterioration of design. The forged bomb was undoubtedly completely satisfactory for all purposes for which it was intended ; the welded bomb far less so ; and finally the cast bomb, in its early stages still less universal, but later to take second place in order of merit. The failure of the united efforts of the best welding firms in the country to produce a satisfactory 'fabricated' body, is of peculiar interest, and a vivid pointer to future designers.

(*c*) As a result of (*b*), the bomb appeared in an unprecedented number of variations (' Marks '). Fourteen of these were in use, and a Mark XV was being developed for under-water use. An appendix is added giving a list of these and a brief comparative description of each.[3]

During the war a greater number of 500 lb. M.C. bombs was released against the enemy than of any other type of bomb, except its counterpart, the 500 lb. G.P., and that only because it could not be substituted for this unsatisfactory bomb in large enough quantities. The enormous demand for 500 lb. M.C. bombs against tactical targets, particularly oil targets, made by the operation 'Overlord,' the liberation of Europe, and the final defeat of Germany, imposed an intolerable strain on the bomb supply resources of the country, a situation which was only saved by the existence of large stocks of obsolete G.P. bombs, all relegated to the scrap heap, but brought back into service to meet the need of the moment. Even with this temporary addition, D.C.A.S. found it necessary to warn the C.-in-C., Bomber Command, in August 1944 of the need for the strictest economy in the use of 500 lb. bombs in the strategical bombing of German towns, and the substitution of incendiary bombs for H.E. to the maximum.[4]

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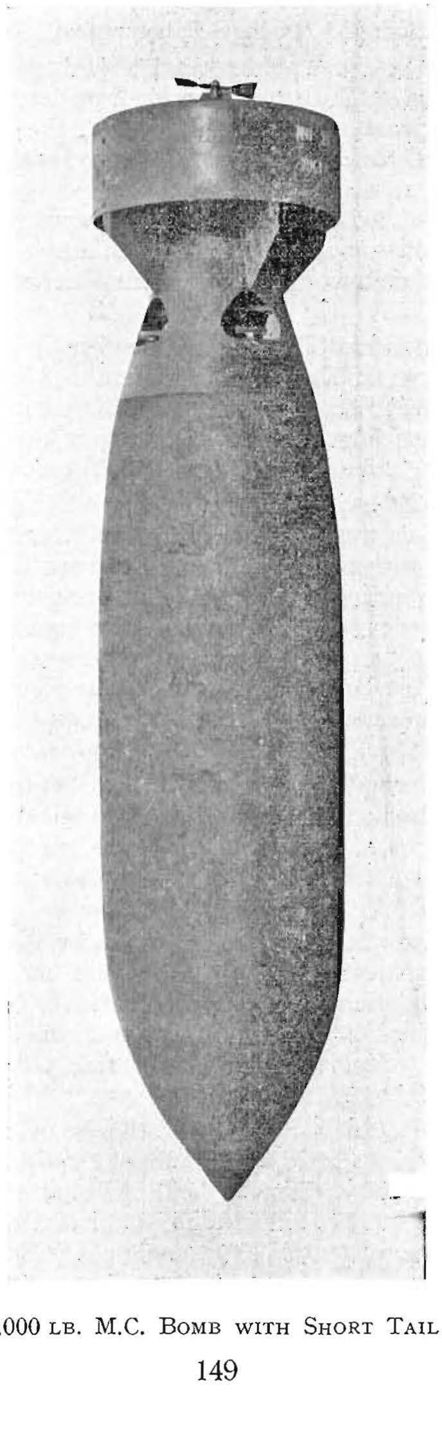
[1] A.M. File S.71783.
[2] A. and A.E.E. Report G.35.
[3] *See* Appendix No. 4.
[4] A.M. File C.S. 22930.

The 1,000 lb. M.C. bomb

On 24 April 1942 D.Arm.D. informed the Ordnance Board that the uncertainty of relying on supplies of bombs of the U.S.A. ' M.44 ' type as a large M.C. bomb has been under consideration, a requirement has been received from the Air Staff that the manufacture of a similar bomb in this country should be



1,000 lb. M.C. Bomb with Short Tail

investigated. The bomb is required to be interchangeable with the M.44 bomb when fitted with drum type units and also with the 1,000 lb. G.P. bomb when fitted with a shortened tail unit.[1]

This information was also sent to C.S.A.D. and went on to say that D.Arm.P. had by then investigated the problem of manufacturing such a bomb by two methods: longitudinal pressings or casting. The latter had appeared most promising and C.S.A.D. was requested to design a bomb for casting, which should as far as possible use standard 1,000 lb. G.P. components.

By 5 May 1942 C.S.A.D. had produced a design (D.D.(L)14458) which provided for the use of G.P. Mark II suspension lugs, detonator holders, and tail cone (with some modification). The thickness of the body wall was to be 0·55 inch, with a 50/50 amatol filling. The total weight was estimated at 1,058 lb., and the charge weight ratio 46 per cent. (The 1,000 lb. G.P. bomb had a wall thickness of 0·77 inch and a charge/weight ratio of 33 per cent.) Immediate arrangements were made for the manufacture of thirty development bombs, and the manufacture of the experimental tail unit for the new bomb was put in hand.[2]

By the end of June successful drop hammer tests of the castings had been completed at Scunthorpe, and arrangements were made for dropping trials by A. & A.E.E. For these, four inert filled bombs were to be dropped against the wall target at Porton from 100 feet at 200 m.p.h., and four on the concrete apron from 2,000 feet. Similar trials from 8,000 feet against the Braid Fell target were also arranged.

The A. & A.E.E. trials were completed on 9 July 1942 and showed that the bomb was capable of withstanding impact with hard targets at low striking velocities without appreciable damage. The more rigorous trials at Braid Fell were completed by the end of July, when eight bombs were dropped from heights of 80 to 8,000 feet on the building target. Five hits were obtained with no serious damage to the bombs. As a result, the adoption of the bomb for service use was recommended by D.Arm.D. in August and approved by the Air Staff in September.

Further trials were completed at Braid Fell in September, this time with bomb cases slightly thinner than those of the original bombs (0·58 inch as compared with 0·65 inch). Except for one bomb which was dropped twice—once from 80 feet and again from 7,000 feet, and which was fractured—all were satisfactory.

Arrangements were now made for ballistic trials by the Orfordness Research Station, although recommendation for service use had already been made. A further batch of bombs was to be used for detonation trials with R.D.X./T.N.T. amatex and amatol fillings. As the bomb, however, was already in production, amatex was chosen as a provisional standard filling, until the results of these trials could be published.

In November the Orfordness Research Station issued its report on ballistic trials carried out with bombs fitted with standard 1,000 lb. G.P. shortened tails. Although the G.P. tail had a diameter less than that of the bomb body the advantage of using a component already in production was great. The trials showed, however, that consistent ballistics could not be obtained with this type

[1] M.A.P. File S.B. 37149.
[2] M.A.P. File S.B. 37149 and Res./Arm. 2785.

of tail. Further trials were therefore necessary with the tail specially designed for the bomb (No. 37). These did not take place until March 1943, when ten bombs were dropped from 10,000 feet. The stability and ballistic consistency of the bomb with its own tail were found completely satisfactory.

In January 1943 the first live trials of the bomb were completed by A. & A.E.E., when five bombs filled with amatex were released from 4,000 feet at an air speed of 150 m.p.h. One was fuzed nose instantaneous, two tail instantaneous and two 0·12 seconds tail delay. The trial showed the bomb to be suitable, detonation was described as satisfactory, and blast was felt at a distance of one mile.

By February 1943 the production of the 1,000 lb. M.C. bomb had reached considerable proportions, no less than nineteen casting firms were producing bomb bodies at a rate rapidly building up to some 18,000 per month.[1] D.Arm.D. therefore felt that it was undesirable to place complete reliance on the products of all manufactures on the evidence of the single test at Braid Fell carried out in the previous July. Drop hammer tests were indeed carried out on samples from all producers, but D.Arm.D. felt that he could not trust this workshop test entirely.

Arrangements were accordingly made with D.Arm.P. for the air test of a proportion of the output of the principal makers. Twelve bombs from each of nine contractors were inert filled and sent for trial to Braid Fell. These tests continued at intervals throughout the year, at first from both low and high altitudes, later from 8,000 and 12,000 to 15,000 feet.

So far only the original design of bomb has been mentioned. The decision to manufacture this bomb by casting rather than forging or welding had been taken because forging capacity was not available, and that employed on the production of 1,000 lb. G.P. bombs not suitable without long and expensive conversion ; nor was the special steel required available.[2] Welding processes were not reliable and bombs produced by this method were suitable only for instantaneous fuzing. By September 1942, however, the demand for the cast bomb had begun to exceed the supply, and D.Arm.P. felt the necessity of turning to other manufacturing methods, and the Director of War Production asked for suggestions on the manufacture of 1,000 lb. bombs by welding methods.[3] The idea was to make up the body in two semi-cylindrical pressings and to weld these by two horizontal seams.

The first bomb, ready in November, was approved on visual inspection by D.Arm.D., and by the beginning of December ten inert filled bombs were sent to A. & A.E.E. for initial supply test at Ashley Walk, where a wall and 'apron' were available for impact tests. At the same time arrangements were made for the despatch of fifteen bombs to Braid Fell for a full scale impact test. It was expected that the new design would compare favourably with the American M.44, on which the design of the 1,000 lb. M.C. bomb had been founded. Trials of the American bomb were staged at the same time for comparison.[4]

The Ashley Walk trials were completed in January 1943 and showed that the welding was satisfactory, although the base plates were torn away by side impact.[5] It was therefore necessary to modify the method of attaching these

[1] M.A.P. File S.B. 37149/2.
[2] A.M. File S. 8012.
[3] M. of S./D.G.W.P., 22 September 1942.
[4] M.A.P. File S.B. 42295.
[5] A. & A.E.E. Report A.T.O.G. 56, 4 February 1943.

before the Braid Fell trials could be undertaken. Some distortion of the nose was also evident, and strengthening here was thought advisable by means of strengthening welts. The attachment of the base plate was strengthened by securing with eight ½ inch bolts. Dropping trials with bombs thus modified were completed on the Braid Fell target by the end of May 1943. Ten bombs were released from 7,000 feet at 150 m.p.h., of which eight struck the concrete building. The noses were severely damaged and the base plates of four bombs were broken away. It was not considered that any bomb would, if fuzed with tail delay, have detonated. It was decided therefore that no further useful purpose could be served in continuing investigation into this method of manufacture : bombs remaining from the original fifty were reduced to produce.

It was unfortunate that research into welding methods for the bomb was thus abandoned, for a crisis once more arose at the beginning of 1945 when it became imperative that such methods must be accepted to improve the supply of 1,000 lb. bombs. Accordingly the welded bomb was rushed into production on similar lines to the Mark I 500 lb. bomb. So great was the urgency that development tests of bombs as they came off production were put in hand.[1] It was however ensured that the welded bomb should be of the best possible construction, in the light of modern welding experience and research, by adherence to the same rigid instructions which had been laid down by the Advisory Council on Welding, set up in 1943, when problems of 500 lb. M.C. manufacture had become acute.[2]

The 1,000 lb. M.C. bomb—forged type

In July 1943 the C.-in-C. Bomber Command wrote to the Air Ministry expressing doubts about the efficiency of cast M.C. bombs fuzed for delay action.[3] As a result, the Command was asked to undertake a series of trials at Braid Fell, mainly for the purpose of testing the various Marks of the 500 lb. M.C. bomb. Included in the syllabus of trials was, however, the 1,000 lb. M.C. bomb, which had only been produced in cast form.[4]

These trials lasted spasmodically until the end of 1944, but by April of that year sufficient results had been obtained to enable a summary to be prepared.[5] So far as the 1,000 lb. M.C. bomb is concerned the following extracts from the conclusions of the Ordnance Board will suffice.

(*a*) The results show that the original M.C. 500 lb. Mark I (welded) and Marks III and IV (cast) are incapable of standing up to severe impact conditions.

(*b*) The M.C. 1,000 lb. bomb, of cast steel, appeared to have performed better than the M.C. 500 lb. of similar construction.

(*c*) It is clear that for the attack of very robust structures, M.C. cast bombs unless fuzed extremely short delay, may break up.

(*d*) A bomb which is liable to break up precludes the free choice of fuzing.

(*e*) The result with the M.C. 500 lb. Mark II (forged) indicated that the body strength is satisfactory . . . : the Board have little doubt that other factories concerned in the forging of the M.C. 500 and 1,000 lb. bombs can reach a similar standard.

[1] M.A.P. File S.B. 42295.
[2] Specification R.D. Arm. 196.
[3] B.C. File BC/S/28522.
[4] M.A.P. File S.B. 51178.
[5] O.B. Proc. 27309.

These results, although published in summary form in April, had been evident much earlier, for on 24 January 1944 the C.-in-C. Bomber Command had asked for a forged 1,000 lb. bomb for his Lancaster and Halifax aircraft.[1]

D.Arm.R., willing to accede, asked D.Arm.D. to organise without delay the preparation of designs and production of such a bomb, and discussion between members of the Ordnance Board, with D.N.O., D.Arm.R., D.Arm.P., C.E.A.D., and D.Arm.D. took place on 5 February 1944.[2] These led to the proposal to Air Staff of two alternatives :—

(*a*) the forging of a 1,000 lb. M.C. bomb with similar design to the existing cast bomb ;

(*b*) a modification to the 1,000 lb. G.P. bomb—a forged bomb—by reducing wall thickness so as to give a charge weight ratio of about 40 per cent. —an increase of 7 per cent. (The forged M.C. bomb—(*a*)—was calculated to have a charge/weight ratio of some 43 per cent.)

D.Arm.R. decided in favour of (*b*) : a point in its favour being the avoidance of further ballistic trials. Filling was to be Minol, or R.D.X./T.N.T. : the maximum permissible weight 1,150 lb. with dimensions not exceeding those of the present 1,000 lb. M.C. bomb.[3]

By the beginning of March 1944, C.E.A.D. had prepared a preliminary design.[4] This showed a bomb on the lines of the 1,000 lb. G.P. with a solid nose and a mean wall thickness of 0·6 inch. About this time production of the 2,000 lb. A.P. bomb at the Royal Ordnance Factory, Cardonald ceased, and it was hoped that the forging facilities thus released might be used for the new M.C. bomb. The project was examined by the Superintendent of the Factory, who concluded that he would be able to undertake the work, although one hundred bombs per week was the maximum possible output. It was therefore necessary to approach civilian firms who might be able to produce the bomb, and D.Arm.P. after investigation was able to report to the Ordnance Board that the firm could produce between them fifty-five bombs each week, making a total of one hundred and fifty-five.

This total was quite inadequate particularly as the Admiralty had stated a requirement for the bomb.[5] There seemed no immediate solution except the standard one of ' fabrication '. C.E.A.D. suggested a forged cylindrical body with a nose welded by what was known as the Union weld method.[6] The Advisory Service on Welding had reported that four machines were available for this method and C.E.A.D. recommended to the Board that a trial of the method was at least worth while.

The Ordnance Board received this suggestion with some indignation and expressed the hope that it would not be necessary to ' stoop to its acceptance '.[7] They insisted on the bomb in its original design, and in some ways this was not surprising, for welding methods in the production of the 500 lb. bomb had been singularly unsuccessful. They recommended immediate commencement

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[1] B.C. File BC/S/30507.
[2] A.M. File C.S. 19955.
[3] M.A.P. File S.B. 55855 and O.B. Proc. 26542/44.
[4] O.B. Proc. 26760 and D.D(L) 18587.
[5] D.N.O. to Sec. O.B., 11 April 1944.
[6] M.A.P. File S.B. 55855.
[7] O.B. Proc. No. 28358.

of the limited production so far arranged. With this D.Arm.D. and D.Arm.R. agreed but were in accord with C.E.A.D. in pressing for an investigation into the proposed welding construction.[1]

C.E.A.D. found himself in entire disagreement with the views of the Board and ' regretted that the Board should wish to discourage a new application of approved technique which offers a possible means of removing some of the bottle-necks associated with the production of bombs which must withstand severe impacts '. He went on to suggest that it was only possible ' to accept the advice of those best qualified to give it ', and argued that the unsatisfactory results of previous efforts at welding should not condemn this new line of approach without a trial.[2] He viewed the action of the Board with concern, and suggested that at least they might agree to give the new method a trial.

After some discussion the Board agreed however to a trial of the new method of welding, so long as it did not interfere with the production of one-piece forged bombs. This opinion was endorsed by the Director of Naval Ordnance, who, however, thought that the new welding method was sufficiently promising to justify a full investigation.[3] Accordingly six steel bodies were earmarked from the first production bombs from R.O.F. Cardonald specially cut to be plain cylinders to receive the welded nose, and arrangements made to carry out the welding, under the supervision of the Advisory Service on Welding. By November 1944 six bombs to which welded noses had been fitted were ready for trial.[4]

Meanwhile production and trial of the original forged bombs had gone steadily forward, and the bomb had been given the designation Mark III. The original arrangement had been that the Royal Ordnance Factory at Cardonald should prepare 100 development bombs for trial. By September 1944, it appeared that this method was a source of delay in production, and D.Arm.D. proposed that all trials should be deferred to allow the Factory to go immediately into production. To these proposals the Ordnance Board agreed. The specification for manufacture was numbered R.D.Arm. 189 and dated September 1944.[5] By that time ten development bombs had been completed at Cardonald : of these six were used for the welding experiment discussed earlier, and four prepared with firing bands for test from a gun at Shoeburyness. The trials in fact did not commence until June 1945, when the first bomb was fired against the ' labyrinth ' target, and were still in satisfactory progress at the end of hostilities in Europe.[6] The development of the bomb then ceased.

Filling.—The original Mark I bombs were filled with 60/40 Amatol, although a number, marked for special operations, were filled with R.D.X./T.N.T.[7] A few early bombs were filled with Amatex, but by the middle of 1943 this filling was abandoned. By far the greater majority were, however, charged with Minol 2.

[1] A.M. File C.S. 8012.
[2] O.B. Proc. No. 28753.
[3] Admiralty No. 8999/44.
[4] M.A.P. File S.B. 55855.
[5] O.B. Proc. 28358/44.
[6] This was an arrangement of armour plates, one facing the gun but at an angle to the line of flight of the projectile, with a second thicker plate behind and at an angle to the first. The projectile penetrated the first or entry plate and struck the second a glancing or side blow. It was then arrested by sandbags. The plate thicknesses were varied according to the requirements of the trial. O.B. Proc. 30800/45.
[7] M.A.P. File S.B. 37149.

Supply.—The 1,000 lb. M.C. bomb proved to be one of the most 'popular' bombs produced during the war: it may in fact be described as the 'standard bomb'. Of the heavy class, that is to say bombs weighing 1,000 lb. and upwards, it had the heaviest consumption. In 1943, the year of its development, Bomber Command dropped 17,500. This figure was increased to 203,000 in 1944. In 1945, 36,000 were released by that Command alone. This enormous consumption of bombs, to which must be added some 30,000 used by the 2nd Tactical Air Force, gave rise to a serious production problem. Air Staff requirements for 1944 rose from 132,000 in November 1943 to 161,000 in January 1944, and to 388,000 in April 1944. With the ever increasing demand, M.A.P. was required to keep in step by home production and an always uncertain supply from America.

In July 1944 Sir Stafford Cripps, Minister of Aircraft Production wrote to the Secretary of State for Air:—

> 'A very serious position had arisen as regards your bomb requirements . . . The difficulty arises from the very great and sudden variation in your demands to us and in addition the sudden complete cessation of U.S.A. supplies.'[1]

The Minister went on to give figures for production and requirements. The output of 1,000 lb. bombs in this country was 18,000 each month, with little prospect of increase. (At this time flying bombs had reduced the output in the London area by 20 per cent. and in this area some 40 per cent. of output was concentrated.) The requirements for the bomb were estimated at 129,000.

The Secretary of State, in his reply, apologised for the ever changing Air Staff demands, due to alterations in the operational role of Bomber Command and a gradual change from the strategic to the tactical role coupled with a tendency to attack precise targets with aimable bombs.

The change from a strategic to a tactical role was, of course, the result of operation 'Overlord,' the invasion of Europe in June 1944. The previous strategic bombing of German cities had called mainly for incendiary and High Capacity Bombs; but since 'D Day' there had been an enormous demand for M.C. bombs for use against tactical targets—oil targets, railway and transport centres and so forth. So great was the demand that it was only by the use of large stocks of obsolete G.P. bombs, ready for salvage, that the bombing effort could be maintained; but the real solution was an increase in the bombs supplied by America.[2]

Meanwhile the Minister of Production put forward a suggestion to increase the output of M.C. bombs by a reduction in that of Target Indicator bombs and hooded flares. A.M.S.O. was not agreeable to this because, in his words, 'if we deprive ourselves of pyrotechnics in order to get more H.E. bombs, the value of the H.E. bombs themselves would be impaired.'[3] There was, however, one other method of improving the situation, and that was to persuade Bomber Command to use less H.E. bombs and more incendiaries. D.C.A.S. wrote to the Commander-in-Chief accordingly, deploring the 'abnormally high proportion of H.E. bombs used in attacks on Kiel, Stuttgart and Hamburg,' and pointing out that 'in the light of the known shortage of 1,000 lb. bombs, the high proportion of these bombs consumed has been noted with grave concern.'

[1] M.A.P. to S. of S., 6 July 1944.
[2] A.M. File C.S. 22930.
[3] A.M.S.O. 126/4, 4 August 1944.

He then called for ' the most rigid economy in the employment of 500 lb. and 1,000 lb. bombs, and for the increased use of incendiary bombs in area attacks.' Further, economy in the attack on Flying Bomb sites must also be observed. ' Experience has shown that the use of large forces against these targets is uneconomical and results in a scale of expenditure of 500 lb. and 1,000 lb. bombs which we can ill afford.'[1]

By January 1945 there had been a little improvement in the situation. No bombs had been assigned from America during October to January, the Americans arguing that ' American requirements as compared with British are directly proportionate to the comparative production of each country.' The C.-in-C., Bomber Command, wrote at the same time to D.C.A.S. that at the present rate of expenditure he would have exhausted the available stocks of 1,000 lb. bombs by the end of March 1945. From all sources the total available by that date was expected to be 103,000, while the estimated expenditure was 180,000.[2]

C.A.S. replied at the end of January 1945 with the proposal that the shortages of 1,000 lb. bombs might be made up to some extent by an unexpected increase in the quantity of 500 lb. bombs available, although some total reduction in bomb weight carried was inevitable as two 500 lb. bombs could not always be carried in place of one 1,000 lb. The position after April was likely to become worse : American allocations were unlikely, none had been made for April and the subsequent months ; moreover, American operations would probably be intensified in the spring and ' the extent to which we can count on them is therefore problematical.'[3] 1,000 lb. and 500 lb. bombs must therefore be reserved for the demand for direct support to the Army expected in spring and summer, and reserves for this purpose must be found at the expense of H.E. used in attacks on communications and the Ruhr area targets. C.A.S. again emphasised the need for the substitution of incendiary for H.E. in area attacks.

These decisions were communicated at the same time to the Deputy Supreme Commander, S.H.A.E.F., who was informed that it might become necessary for Bomber Command's role to be modified to the extent that ' outside the communication area immediately related to the land battle, communication centres will have to be dealt with by area attack rather than by attacking the marshalling yards, junctions, etc., associated with them.'[4]

In spite, however, of economies by Bomber Command, and every effort to increase production at home, Air Ministry was obliged to signal to the R.A.F. Delegation in Washington on 17 March 1945 that ' the joint R.A.F./U.S.A.A.F. 500/1,000 lb. M.C. bomb supply is critical in the extreme. Spaatz has made the strongest personal representations for R.A.F. assistance which is being given to the limit. Eisenhower has signalled Marshall emphasising gravity of U.S. Forces bomb supply situation.[5] By the end of the month (March) Royal Air Force stocks in the United Kingdom will be only 23 days' expenditure ; holdings will be less than those required at Bomber Command Stations alone. Vital that maximum tonnage of these bombs be shipped to the European Theatre forthwith.'

[1] A.M. File C.S. 22930.

[2] A.M. File S. 91365.

[3] C.A.S. 390, 27 January 1945. As a result of an appeal by General Eisenhower, production had been increased in the U.S.A. but even then the American Naval and Army requirements could scarcely be met. By February, Washington tentatively assigned 10,000 bombs.

[4] V.C.A.S. to Deputy Supreme Commander, 2 February 1945.

[5] Webber W. 2505, 17 March 1945 and A.M. File S. 95113.

The reply to the signal from which extracts have been quoted was not optimistic. It was to the effect that the American factories could do no more than was already being done and that General Eisenhower must make the best use he could of transfers within his theatre of operations. The quantities which could be shipped from April production were estimated at one hundred and eighty thousand 500 lb. and thirty-seven thousand 1,000 lb. bombs, and the Supreme Commander was asked to state what proportion of these he wished to assign to the Royal Air Force.[1] The complete change in the war situation in May 1945 relieved the general anxiety about supply.

The 4,000 lb. M.C. bomb

On 12 May 1942 the C.-in-C., Bomber Command, wrote to the Air Ministry and stated his need for 'a large bomb with a high blast performance which can safely be dropped from as low a height as 100 feet.'[2] The targets for which the bomb was required were primarily light and heavy industrial plants, aircraft and engineering factories and shipbuilding yards.

The C.-in-C. acknowledged the existence of both the 4,000 lb. G.P. and H.C. bombs which were available for his purpose, but pointed out that the charge/weight ratio of the former was too low, while the latter would probably break up even from very low heights. He ended his letter by requesting that this urgent requirement may be met by the production of a 4,000 lb. M.C. bomb accommodating the normal range of G.P. fuzing and capable of fitting into the existing 4,000 lb. H.C. stowage of all the aircraft concerned.

D.O.R. acknowledged both the need for such a bomb and the inadequacy of the two possible substitutes mentioned, and after preliminary discussions with representatives of D.Arm.D. decided not to recommend the development of a new bomb until the use of four 1,000 lb. M.C. bombs to serve the same purpose had been fully examined. Bomber Command, however, pressed for the immediate development of the 4,000 lb. M.C. bomb as a definite requirement for the attack of shipyards, expressing doubt about the relative efficiency of four 1,000 lb. bombs.[3]

The shipyard target was a new argument and A.C.A.S.(T) consented to ask C.R.D. to authorise the manufacture of two hundred bombs to a sketch prepared by D.Arm.D. The charge/weight ratio aimed at was 50 per cent. The trials of the bomb were to be operational, and C.R.D. promised at least some of the two hundred by the end of the year. Production of the development bombs was not, however, all plain sailing, as a conflict on priority arose between the new bomb and the 'J.W.',[4] a bomb which the C.-in-C., Bomber Command, was also anxious to have. The two bombs were being produced by the same firm. The C.-in-C., Bomber Command, after protest at what he thought an unnecessary conflict of priority, agreed to the production of 500 J.W. bombs at the expense of the new M.C. bomb.

The 4,000 lb. M.C. body was 'fabricated' and was similar in construction to the 500 lb. M.C. Mark I. The wall was of $\frac{3}{4}$ inch steel plate welded into a cylinder, with nose and tail sections welded into position. A special tail was

[1] Marcus 2574, 31 March 1945.
[2] A.M. File C.S. 14772.
[3] B.C. File BC/S/26920.
[4] 'Johnnie Walker', a bomb designed to rise and fall in harbours, for the destruction of shipping. A.M. File C.S. 14772.

similar in design to that of the 4,000 lb. G.P. bomb. In the original bomb, fuzing at both nose and tail was provided. The bomb was of such size as to be capable of fitting into the 4,000 lb. H.C. stowage position.

By the end of September 1942 a prototype bomb and tail were completed and sent to A. & A.E.E. for installation trials in the Halifax, and at the same time D.Arm.D. asked the Ordnance Board for their views on detonation and other trials, and on filling and explodering.[1] The first trials of the bomb, manufacture of which proceeded without difficulty, were completed on 24 October, when four inert filled bombs were released from 70 and 1,000 feet against the concrete apron and walls at Porton. Live detonators were placed in the tail and the noses were plugged.[2] No bomb was damaged, but one failed to arm, and A. & A.E.E. suggested as well as modification to the tail pistol, the provision of additional fuzing positions on the tail. Ballistic qualities were good. The bomb was thus proved to be reliable against concrete.

By the beginning of December, C.E.A.D. had prepared a method of filling design.[3] Particular attention was to be paid to the interior of the nose, which was strengthened by internal webbing ; smoothness of all contours was essential. For early detonation trials the bombs were filled Amatex.

By the middle of January 1943 D.O.R. was able to inform Bomber Command that fifty bombs were ready for despatch to Maintenance Units for operational use. The trials already completed had been against concrete only ; and there had been no time for more rigorous tests, even if suitable experimental targets could be found. The Command was therefore asked to obtain all possible information from photographs and assessments of damage so that a decision could be made about future production. Meanwhile, two important trials had been made by A. and A.E.E. In December 1942, two bombs filled with Amatex were released from 4,000 feet with short delay (0·12 sec. and 0·25 sec.). One unfortunately failed to detonate because of a broken fuzing latch on the carrier : the second made a large crater in blue clay and marsh of 70 feet diameter and 40 feet depth. The bombs were exceptionally stable in flight. A second trial was made in January 1943 to test various kinds of wire for American type fuzing. Twelve inert bombs were released, six after flight with the bomb doors open. The trials showed that American wire and clips were superior to the British. They further showed that the bomb remained ' safe ' in the aircraft with American fuzing : that four arming vanes were necessary for effective arming from heights of 100 to 500 feet : moreover from 100 feet the bomb failed to ' detonate ' with impact on a horizontal surface whereas at 500 feet detonation was achieved. As a result, arrangements were made for the manufacture of wire and clips to the American design and for the fitting of four vane pistols to all 4,000 lb. M.C. bombs.[4]

By the end of February the operational report on the bombs was not available as none had then been used. The reason for this was that carriage was limited to Lancaster C.S. aircraft which were then—owing to their small numbers—engaged on carrying 8,000 lb. H.C. bombs. The 4,000 lb. M.C. bomb could not

[1] M.A.P. File S.B. 39566.

[2] A.M. File C.S. 14772.

[3] A. & A.E.E. Report A.T.O./04, 9 November 1942, D.D.(L) 15478 and O.B. Proc. Q.845/42.

[4] A.M. File C.S. 14772. Fuzing by means of flexible wire from the pistol to a central point on the bomb and then up into the carrier. The wire is attached by a clip to the arming vane.

be carried in the standard Lancaster until that aircraft had been suitably modified. By June 1943, a small number had been used by Bomber Command, but the original requirement for the bomb had apparently been forgotten, nor had any test such as D.O.R. had asked for, been made. They had in fact been used as H.C. bombs from high altitudes in area attacks and no determination of their effect had been possible. In that month a request for trials to show the effect of the bombs on roads, and especially on buried water and gas pipes and electrical cables, was made to the Ministry of Aircraft Production by the Command, who offered to provide the aircraft if M.A.P. could find a suitable target. The new requirement was supported by D.O.R. who advocated the testing of the bomb as a rival to the 4,000 lb. H.C. bomb, for detonation, after deep penetration, in the general bombardment of towns, not only of roads.[1]

The difficulty was to find a suitable target, but even if this had been found the expenditure of very many bombs would probably have been necessary before a satisfactory hit was obtained. The best that could be done was to choose the hardest natural target available on an established bombing range and to drop bombs on it from a comparatively low height. This was in fact done on a gravel-flint portion of Ashley Walk range, when A. & A.E.E. dropped two bombs from 5,000 feet in July 1943. One bomb had a tail delay of 0·025 second, and the other tail instantaneous fuzing. Both detonations were satisfactory, giving craters of 54 feet wide by 14 feet deep and 36 feet by 10 feet respectively.

There was, of course, the possibility of an enemy target, such as one likely to be overrun at some reasonably later date, for subsequent examination or dropping a bomb 'inert' on to an already captured target. Twelve bombs were accordingly sent to the Mediterranean in the hope that a suitable target might be found there.

This proposal was readily accepted by Mediterranean Command who promised to give every assistance in assessing damage and performance against resistant targets, but unfortunately the high hopes were not fulfilled. In February 1944, the Deputy Air Commander-in-Chief was obliged to inform the Air Ministry that no trials had been possible as no suitable target had yet been available. The twelve bombs were eventually dropped on operations but no detailed report of their effect was made as it was found to be indistinguishable from that of other bombs released at the same time.[2] There was no alternative therefore, if a proper estimate of the efficacy of the bomb was to be made, but to drop them inert on the Braid Fell target, although this gave proof only of the ability of the case to stand up to punishment. Samples were therefore included in the long series of trials on this target undertaken by Bomber Command between October 1943 and October 1944.

The 4,000 lb. bomb was tested at Braid Fell between 6 and 22 April 1944 when three hits were obtained on the building from 100 feet at 275 m.p.h. The trials proved that the bomb was capable of resisting the girder and concrete structure of the target, except for the base plate which tended to be torn away. D.Arm.D. consulted the Chief Engineer of Armament Design who prepared a

[1] It was at this time that the possibility of 'earthquake effect' came to be discussed by Mr. Wallis, Chief Designer of Messrs. Vickers, leading eventually to the production of Wallis designed bombs of enormous size and capable of extremely deep penetration, to be described later under the picturesque names of 'Tallboy' and 'Grand Slam'. A.M. File C.S. 14772.

[2] A.M. File C.S. 14772.

strengthening design with additional holding down bolts. At the same time other modifications to the bomb were thought advisable, particularly the design of the nose and the method of welding the various components of the bomb body.

The original nose had been made up in ogival form in two parts, welded together, the whole being then welded to the cylindrical part of the bomb. It was now proposed that the nose should be formed from a single steel plate, the shape being reached by spinning. With the adoption of the one-piece nose, nose fuzing arrangements in the new design were abandoned and a special plug was provided to close permanently the nose. The bomb with these various modifications was given the distinguishing name of Mark II. The design was formally introduced into service in September 1944.

Bomb Filling.—The original filling of the 4,000 lb. M.C. bomb was Amatex (ammonium nitrate 50 per cent., T.N.T. 41 per cent., R.D.X. 9 per cent.), but far the greater number were eventually filled with Minol 2.[1]

Quantities.—During the war over twenty-one thousand 4,000 lb. M.C. bombs were dropped by Bomber Command, of which thirteen thousand were used in 1944. The large discrepancy between these figures, and those of British production already mentioned, was accounted for by American manufacture.

A Summary of M.C. bomb efficiency

Post-war investigation into the relative value of M.C. bombs up to 1,000 lb. and H.C. bombs against towns, heavy and light industrial targets, oil targets and marshalling yards resulted in the following conclusions :—[2]

M.C. bombs against domestic buildings

Variations in bomb effectiveness from incident to incident, in the quality of air photographs, and the relationship between categories of damage established from air photographs and from ground surveys, made measurements of weapon effectiveness against houses, from air photographs, rather unreliable.

Insufficient ground surveys of the effects of British and American bombs against German housing are available to enable any conclusions to be drawn from them. They are sufficient however, to confirm the considerable superiority (shown in blasts tests and in the effects of German bombs on this country) of large H.C. bombs over the smaller M.C. types.

M.C. bombs against industrial buildings

From data on German bombs on British buildings, from air photographs and ground surveys in Germany and France, it was apparent that against single-storey industrial buildings 500 lb. and 1,000 lb. M.C. bombs are very inferior per ton to the large H.C. bombs. The data on multi-storey industrial buildings was not so complete but suggested that there was little to choose per ton between M.C. bombs and the larger H.C. types.[3]

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[1] M.A.P. File S.B. 39923.
[2] B.B.S.U. Weapons Effectiveness Panel. D.G.Arm. W.E/S. 3507.
[3] *See* Chapter 11.

M.C. bombs against bridges

Against steel bridges it is concluded that the 500 lb. bomb was, per ton, the most efficient for causing traffic delay. On the other hand for complete destruction of at least one span there was little to choose between the 1,000 lb. and 12,000 lb. bomb, both of which were considerably more effective than the other sizes of bomb used.

For brick and masonry and bridges it was concluded that the 12,000 lb. bomb was considerably more efficient per ton for causing traffic delay, and that there was little to choose, per ton, between the 1,000 lb., 2,000 lb. and 12,000 lb. size for causing the destruction of at least one span.

M.C. bomb against machine tools

Although a study of the report showed that generally there was no marked difference in the effectiveness per ton of H.E. and incendiary bombs, a few points of interest regarding M.C. bombs are noted.

It was shown that for bombs 500 lb. to 2,000 lb. with an explosive content of 30 per cent. to 55 per cent., *i.e.*, M.C. category, direct hits on machine shops with bombs which had their fuze initiated on the roof and then detonated above floor level (air burst) were about three times as effective as bombs which formed craters on the floor.

There was no significant difference in effectiveness per ton for bombs between 500 lb. and 2,000 lb. Insufficient data was available for any conclusions to be drawn on larger bombs.

Effects against oil targets

The effectiveness of the different sizes of bomb used for causing physical damage decreased with increasing bomb size. The lightest bombs used (250 lb.) were nearly twice as effective per ton as the heaviest (1,000 lb.). It was emphasised that production loss, rather than damage, was the object of air attack, and that unfortunately the data and time available did not permit of a production loss analysis being made. It was thought possible that the larger bombs would show up more favourably as to production loss, due to their tendency to destroy a large proportion of one process rather than smaller proportions of several processes.

CHAPTER 11

THE HIGH CAPACITY (H.C.) SERIES

The bombing of London and other British towns which commenced on what was then considered a large scale in the winter of 1940 provided the best measure yet available of the effect of H.E. bombs on structures. From the results obtained, particularly against domestic and low factory buildings, it was evident that the effect of blast was far greater than had been anticipated. The low single storey factory with roof spans generally not exceeding 60 feet, and gantry cranes, is probably the commonest type of industrial building in England, and is used for all types of light and general engineering. In such buildings confined blast proved to be the only really efficient means of producing widespread damage. The German S.C.[1] bombs and particularly the parachute mine, so often erroneously described as a 'land-mine', which were used almost exclusively, left no doubt about the type of bomb for maximum damage to structures unless heavily reinforced and strongly subdivided.

British development of blast bombs had been confined almost entirely to bombs for under-water attack. The whole G.P. range was an unfortunate compromise between strength of case and weight of explosive. 1940 saw the beginning of a long range of blast producing bombs from 2,000 to 12,000 lb. The idea was not however, an entirely new one in British bomb development. In 1918 two blast bombs were designed, weighing 1,700 lb. and 3,300 lb., for the bombing of German industrial centres by the Independent Air Force.[2] These were true blast bombs, having a light cylindrical case and charge weight ratio of 50 per cent. The smaller bomb was used with some effect against targets in Germany particularly airship works at Kaiserslautern; the larger bomb was never used, and after the war, the blast bomb, except for under-water use was abandoned in favour of the G.P.

The development of the blast bomb began in the autumn of 1940, the first size to be considered being the 4,000 lb. bomb, although this was followed almost immediately by a 2,000 lb. bomb. It will therefore be convenient to deal with this series in order of the four sizes which were eventually brought into service—2,000 lb., 4,000 lb., 8,000 lb., and 12,000 lb. As the 4,000 lb. bomb and its successors involved an entirely new principle in bomb design—the building up of a bomb in sections—the series has special interest.

The 2,000 lb. H.C. bomb, Mark I

In October 1940 the Director General of Research and Development ruled that development of a 'blast' bomb should commence immediately. The requirements for the new bomb were that it should be cylindrical in shape and have the highest possible weight of charge. As the case must be of the lightest possible structure, impact on hard targets must be reduced to prevent premature breaking up, and, to keep the striking velocity low—250 feet per second was aimed at—a parachute or drogue was required. The diameter was to be similar to that of the 1,900 lb. G.P. bomb (18·7 inches) and the length to be such that

[1] Spring Cylindrisch.

[2] The so-called 'S.N.' bombs, for the bombing of Essen.

the final weight should not be less than 2,000 lb.[1] Stowage on all aircraft capable of carrying the 1,900 lb. G.P. bomb was required without modification to the aircraft. Fuzing in the first place was to be confined to direct action, but, as in the 4,000 lb. bomb whose design had commenced a month earlier, provision was to be made for alternative delays, and for special long delay and anti-disturbance fuzes.

These requirements were sent to the Ordnance Board in October 1940 by the Director of Armament Development, who decided that the bomb case design should be undertaken by Messrs. Vickers Armstrong Ltd. and that of the parachute attachment by the Royal Aircraft Establishment.[2] Both Vickers and R.A.E. were asked to collaborate with the Chief Superintendent of Design who was designing the 4,000 lb. blast bomb. The new bombs were given the name ' High Capacity ', abbreviated to ' H.C.'

By the beginning of November C.S.D. had produced a sketch design, and on the 22nd of that month the Director of Operational Requirements was informed of the development, and immediately an experimental order was placed for fifty bombs for fragmentation, blast pressure and dropping trials.[3]

By the end of November the new bomb was formally made an Air Staff Requirement, and the proposed uses to which the bomb was to be put were formulated.[4] These were :—

(*a*) The attack of shipping in basins, docks and anchorages.

(*b*) The attack of aqueducts and canals.

(*c*) The damage of suitable land targets by blast.

From this list it will be seen that the bomb was regarded at the outset as a mine, and that its use against targets was a subsidiary one.

The Air Staff imposed somewhat more stringent conditions for the fuzing of the bomb. Its case was to be sufficiently strong to give complete detonation from heights of 500 feet and upwards with D.A. fuzing, without a parachute.[5] For delay detonation a parachute was permitted, the delays suggested being 0·5 seconds, 30 seconds and 30 minutes, with acceptable tolerances on the latter two times of 33 per cent. and 50 per cent. respectively.

The possible need for alternative delays had been anticipated, and the early model of the bomb was equipped with a nose fuzing position to accommodate a D.A. pistol, and four side pockets or explode tubes at the rear to accommodate alternative delay components or any other special fuzing device which Air Staff might require. In later marks these complications disappeared. The Mark II bomb had three fuzing positions in the nose so that the direct action pistol and detonator could be triplicated, and the possibility of a blind through faulty initiation reduced ; in the Mark III bomb the construction was similar, but the two outside pockets were permanently plugged, and a single pistol and detonator used.

In December a schedule of proposed trials for the new bomb, and its companion the 4,000 lb. size, was drawn up by D.Arm.D. and approved by the Ordnance Board. Twelve bombs were required ; eight inert filled for tests of

[1] This length was limited to 122 inches for stowage on Stirling, Halifax, Hampden and Manchester.

[2] M.A.P. File S.B. 12297/1.

[3] M.A.P. File S.B. 12297.

[4] A.M. File S. 7282.

[5] Direct Action.

body strength and parachute opening by the Aircraft and Armament Experimental Establishment, four H.E. bombs for static detonation and live drops, by C.S.R.D. and A. & A.E.E., and a space model for stowage trials at A. & A.E.E. By the beginning of that month R.A.E. had completed the design and drawings of the parachute containers to be attached to the tail of the bomb. The Chief Superintendent was asked to provide ten complete parachute assemblies for the trials. By the middle of December 1940 the first three empty bombs were ready, and by the beginning of January twenty-three were completed and H.E. filling at the Royal Ordnance Factory, Hereford, had commenced.[1]

Early in January 1941 dropping trials of six inert filled bombs were completed, for the testing of drogues and parachutes. Two bombs fitted with parachutes proved to be unstable from 800 and 2,000 feet. The other four were fitted with drogues of various sizes with shroud lines of various lengths and these were more successful, a stable trajectory being achieved with a 3 feet 6 inch diameter drogue attached by 4 feet 6 inch lines.[2] More trials were, however, considered necessary before the design could be approved, particularly as stowage difficulties in the Hampden had been met by A. & A.E.E. and some modification either to the bomb doors or to the bomb would be necessary, and no detonation or other live trials had yet been attempted. In spite of this the Vice Chief of Air Staff decided that orders both for this bomb and the 4,000 lb. size must be placed for service use.

Further stability trials with drogues and parachutes were completed at Porton early in February, during which a small ballistic cap was fitted to the nose of the bomb, to extend its cylindrical shape to its full length. They proved the parachute to give greater stability than the drogue, especially when the lines were attached to the extreme rear of the bomb, also to reduce the striking velocity sufficient to prevent breaking up on impact with a soft target. On 19 February, further trials with a 5 feet 6 inch parachute were completed, including one live drop from 4,000 feet, at Ashley Walk range. The bomb detonated on impact giving a crater of 20 feet by 4 feet and a clear swept area of 70 yards diameter.

By the end of February D.Arm.D. had decided that with some small modifications to the parachute attachment and improvements in the quick attachment of the parachute container, the bomb should go into production, and the Director of Armament Production was asked to place a preliminary order for 4,500.

In April, trials of the bomb fitted with 'Spoiler rings' were concluded by A. & A.E.E. These rings, designed by R.A.E. for both the 4,000 and 2,000 lb. bombs, were intended to increase the drag of the bomb in conjunction with the parachute, in order to limit the striking velocity. Two sizes of ring, one projecting 3 inches and the other 5 inches beyond the junction of body and nose, were tried with equal success, the bombs falling with a steady oscillation through 10°. By that time the 4,000 lb. bomb had been successfully fitted with a drum type tail, and D.Arm.D. commenced an investigation into the possibility of a similar tail for the 2,000 lb. size, which would eliminate the complicated parachute. In any case the parachute used with the bomb was still not completely satisfactory both as regards attachment and material, and R.A.E. were constantly engaged in experiments to improve both. The fitting of the parachute container to the bomb particularly gave great trouble, and was the cause

[1] M.A.P. File S.B. 12297.

[2] A drogue is an open sleeve either cylindrical or conical.

of numerous complaints from those operational Bomber Stations to which the early bombs were sent. Units were compelled to spend several hours on each bomb in modifying the fitting, and conditions were so bad that a representative of D.Arm.D. was sent to Bomber Command to carry out a special investigation. Bad manufacture and finish were the immediate causes, coupled with indifferent inspection. A re-inspection of all bombs at the filling factory Hereford, at Maintenance Units and at Bomber Command Stations was ordered. At the latter it was found that 115 bombs needed modification and quick arrangements for the work to be done by a local firm were made.[1]

These manufacturing troubles, and the undesirability of using a large bomb with a parachute attachment, which made accurate aim impossible, revived the need for a ballistic tail of orthodox design. The possibility of fitting such a tail had already been examined by D.Arm.D. in April 1941, when the dimensions of the bomb were governed by those of the 1,900 lb. G.P. bomb, to which the 2,000 lb. H.C. bomb was regarded as an alternative. These allowed for a drum tail of only 20 inches long, while the ballistic experts considered that a 50 inch tail would be the minimum necessary for stability. The matter was allowed to rest there, and the 2,000 lb. bomb was introduced into the service in January 1942, with parachute attachment only.[2] By that time the original requirements for the fuzing of the bomb had been modified. Bomber Command no longer required any delay action in the bomb, and the side pockets which had been designed in the tail end of the body became unnecessary. In December 1941, the contractors were informed that these pockets need no longer be fitted.

With the disappearance of the requirement for delay went the necessity for a very low striking velocity, and the way was then clear for the fitting of an orthodox tail to the bomb in place of the parachute. A drum tail was designed during the early months of 1942 by the Armament Department of A. & A.E.E., and ballistic trials gave satisfactory results.[3] The tail was attached to the bomb by a fitting similar to that which had been used for the parachute. The tails were sufficiently rigid for ordinary handling, and the attachment simple and satisfactory. A terminal velocity of 830 feet per second was calculated from comparative drops with 500 lb. G.P. bombs, the nose spoiler ring being retained.

Meanwhile a redesign of the bomb was under consideration, the welding of the original bomb had been a source of trouble and it seemed, with the disappearance of the parachute and no requirement for delay action, that there was a need for a simplified Mark II design. By the middle of 1943 the Mark I bomb had been declared obsolete, and its place taken by the Mark II design.

The 2,000 lb. H.C. bomb, Mark II

The abandonment of the parachute tail in the original 2,000 lb. H.C. bomb had increased its operational value greatly, but there were several details of design which needed improvement. Welding had been difficult, as some of it had had to be done inside the bomb, requiring the services of welders of small stature. The method of attaching the tail unit had been unsatisfactory as an effort had been made to use the original parachute attachment. A more satisfactory attachment had been designed for the 4,000 lb. H.C. bomb. Accordingly, in July 1942, D.Arm.D. requested the Ordnance Board to have drawings prepared of a new design which would eliminate the difficulties already

[1] M.A.P. File S.B. 12297/2.
[2] Res. Arm. 1653, 20 January 1942.
[3] A. & A.E.E. Report A.7.10.G.28, 28 June 1942.

mentioned, and of an outline which would improve the bomb for stowage in aircraft.[1]

Briefly, the main differences between the new bomb and the Mark I design were :—

Reduced length. (The length of the Mark I bomb with tail was 161·5 inches : the length of the Mark II was 130·4 inches.) The inclusion of three exploder pockets in the nose. This arrangement had been used in the 4,000 lb. bomb, and was designed to eliminate the possibility of failure through faulty detonation. The attachment of the tail by means of bolts to a locking ring instead of by bayonet joints.

The ballistic trials were completed in November when four bombs were released singly from a Halifax, each simultaneously with a 250 lb. G.P. bomb, from approximately 5,000 feet.[2] In loading, prior to these trials, difficulty was found in fitting the bomb-tails, due to faulty experimental manufacture, but the ballistics of the bombs appeared good. The terminal velocity was calculated at about 800 feet per second. As a result, arrangements for production were put in hand immediately by D.Arm.D.[3]

By February 1943, a quantity of the new Mark was ready for filling. Unfortunately it was found that the arrangement of three pockets in the nose of the bomb—one central, and two at an angle to the length of the bomb—created serious filling difficulties. To avoid delay, therefore, the two radial exploder pockets were sealed off, and instructions sent to users that the bombs were to be fitted with a single, central exploder system only.

It was indeed very doubtful whether the fitting of three fuzing systems was justified.[4] The Mark I bomb had had a single nose pistol. By the end of 1941 Bomber Command had dropped two hundred and twenty-six 4,000 lb. H.C. Mark I bombs, which also had a single nose pistol, and ninety-seven 2,000 lb. H.C. Mark I, and the few recorded failures were either doubtful or put down to other causes than a detonator failure. It thus appeared that the multiplication of fuzing system, with its extravagant expenditure of pistols, exploders and detonators, and its complication of manufacture, could scarcely be justified.

This view was not, however, shared by D.Arm.D., and immediate steps were taken to modify the construction of the exploder pockets so that fitting and sealing could be carried out effectively. The concession to blank off the two outside exploder pockets was limited to some 1,200 bombs.[5] The modified bomb was known as Mark III, identical with Mark II except that three fuzing positions were used.[6] The manufacture of the bomb went ahead smoothly enough, although not entirely free from the usual small difficulties of welding, tolerance and alignments.[7] Both Marks II and III were formally introduced into the service in June 1943.

[1] O.B. Proc. 18773/42.

[2] A. & A.E.E. Report A.T.O. G.28, 6 December 1942.

[3] O.B. Proc. 21094/43.

[4] O.B. Procs. 21327/43, 21813/43 and Q. 310/41.

[5] A.M. File H.S. 67080.

[6] *See* Method of Fitting, D.D.(L) 15363A. Modified by Sketch AO/896, M.A.P. File S.B. 38735.

[7] A good deal of welding was necessary. A steel block was welded to the inside of the bomb at the suspension point : a T section ring was welded round the inside of the bombs and two channel section beams were welded longitudinally to the inside, all for stiffening purposes. The conical nose was welded to the cylindrical body, and into this was welded an exploder container. An angle ring was welded to the inner wall of the cylinder close to its rear end to which a closing plate could be bolted. There were various other small items welded to the outside of the bomb.

The Mark III bomb was fitted with three exploder and pistol pockets in the dome shaped nose, although only the centre position was used in the Mark II bomb, and this led to some complication in fuzing control. Each pistol had to be connected by a fuzing link to a fuzing box on the bomb carrier, so that the bomb might be released either in a safe or a live condition. Only one such box was provided on the standard carrier, while three pistols had to be connected to it.

Trials of a system of three flexible wires, all joined to a single short flexible link, running to the fuzing box on the carrier, were completed at A. & A.E.E. in June and August 1943.[1] These trials showed that the most satisfactory arrangement was one in which all fuzing links were flexible, and all the same length. They also proved that in any case the bomb could not be dropped 'safe' from greater heights than 700 feet on hard ground, as the impact was sufficient to shear the safety fork.

The filling of the bomb calls for no special remark ; 60/40 or 50/50 amatol was used throughout, and C.E. exploders were fitted. The 2,000 lb. H.C. bomb, the smallest of the 'blast bombs,' was used extensively throughout the years 1942 to 1945. In all, 28,633 were released over enemy territory, nearly 15,000 of these being released in 1944. As to the effectiveness of this size of H.C. bomb, the reports by the British Bombing Survey Unit issued in 1947 do not include the 2,000 lb. bomb, but some interesting extracts concerning the larger sizes is to be found at the end of this chapter.

The 2,000 lb. bomb marked a definite, but temporary, departure from what may be described as orthodox bomb design. It was cylindrical in shape, and had no tail fins. Its ballistics were thus poor, and the fitting of a 'spoiler ring' round the nose was an attempt to stabilise the flight of the bomb. Another innovation associated with this and successive H.C. bombs was the use of protecting rings: these were rings of 'U' or tubular section, made in two halves, which were clamped round the bomb near the nose and tail and which served as a protection during storage and transit, when the extremely thin case (½ inch) was liable to damage.

The 4,000 lb. H.C. bomb

The 4,000 lb. H.C. bomb was the first of the large blast bombs to be designed, although its requirements were formulated only some weeks earlier than those for the 2,000 lb. bomb. It was also the first of the really large bombs to be used, although again, it was followed quickly by the 4,000 lb. G.P. bomb, and was the largest bomb which had ever been released by the British Air Force at that time.

In September 1940 D.Arm.D. wrote to the Ordnance Board to announce the Air Staff requirement for a new 'mine-bomb' to weigh some 4,000 lb., and to invite representatives to a meeting at M.A.P. to discuss design and manufacture. The requirements were :—

(*a*) Carriage in Wellington aircraft with a modified bomb bay ; also in the Stirling and Halifax, but the latter was not to prejudice design or early completion.

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[1] A. & A.E.E. Report A.T.O. G.28, 25 August 1943.

(*b*) Attacks against—

(i) Shipping in docks and anchorage.

(ii) Aqueducts and canals.

(iii) Suitable land targets, *e.g.*, oil plants.

(*c*) Of sufficient strength to permit dropping from heights up to 1,500 feet at 200 m.p.h. without breaking up.

(*d*) Variable fuzing, either Instantaneous, Delays of 5 seconds, 30 seconds, or 30 minutes, or Magnetic. (Tolerances for the delays were as for the 2,000 lb. bomb.)

The meeting took place on 18 September 1940, with representatives from the Admiralty, Air Staff, M.A.P., C.S.D., and the Ordnance Board.[1]

The Director of Torpedoes and Mines (D.T.M.) (Admiralty) considered the bomb extravagantly large for the attack of surface ships, and certainly too large for Fleet Air Arm aircraft. It was therefore decided that the mine and bomb development should be entirely separate, C.S.D. to design the bomb and D.T.M. the mine, if the Admiralty should decide that such a mine was required. The Ordnance Board was to be responsible for the filling and detonation systems. The filling of the bomb was discussed, and it was agreed that amatol would have to be used, although, particularly for the mine, T.N.T. or R.D.X. would have been preferable. At that time, however, the supply of either of these in quantity was doubtful.

Primary attention was to be given to the installation of the bomb in the Wellington. The project was taken up enthusiastically by Mr. B. N. Wallis, the chief designer of Messrs. Vickers Armstrong Ltd., who, since 1938, had been the advocate of larger bombs and aircraft.[2] The name of Wallis will appear later in bomb history in connection not only with large bombs, but with special bombs used for the destruction of German dams. Wallis was approached by the Deputy Director of Research and Development (Arm) in July 1940, on the question of the 4,000 lb. bomb in the Wellington, and gave the opinion that the modification could be completed in six weeks.[3] Meetings were held at Messrs. Vickers Armstrong works at Weybridge to discuss the carriage of the proposed new bomb on 9 and 14 October, when various details of installation and hoisting were discussed, and a week later after this timid approach, D.G.R.D. ruled that all Merlin Wellingtons 'not in too advanced a state of manufacture' should be modified to carry the new bomb.

As with the 2,000 lb. H.C. bomb, R.A.E. were asked to design a suitable parachute, and at a meeting held by D.Arm.D. in October 1940 to discuss the details of the bomb, C.S.D. produced a sketch design of the proposed bomb body. It was then decided that it would not be possible to include provision for a magnetic firing system, a decision with which D.T.M. had already agreed in preliminary discussion.[4]

The Air Staff's very complicated requirements for fuzing were discussed at length, and it was decided that a direct action nose pistol was to be provided in the nose, but the striking velocity of the bomb was to be such that this pistol (a No. 27) would operate on land but not on water.

[1] M.A.P. File S.B. 11217/1.
[2] A.M. File C.S. 8640.
[3] M.A.P. File S.B. 11664.
[4] M.A.P. File S.B. 11217.

For the delay requirements, four axial exploder pockets were to be provided. These would be fitted with :—

(*a*) A 0·5 second 'All-ways' pistol.[1] This already existed and was used in incendiary bombs.

(*b*) A 30 seconds delay pistol which would have to be designed.

(*c*) A 30 minutes delay pistol which again would have to be designed, although a similar type was in existence.

(*d*) A non-disturbance or very long delay pistol (designs for both these were then under investigation).

In later designs these complicated requirements were abandoned in favour of a simple nose pistol ; yet another example of the importance of simplicity of design, for efficiency and speed of production. The meeting finally decided that R.A.E. must also investigate the effects of fitting a ballistic tail instead of a parachute when the bomb was used for D.A. blast purposes, as the use of a parachute put any possibility of accurate aim out of the question, and C.S.D. was to design a suitable tail.

Arrangements were made for the construction of the first bombs, commencing with a 'space model' of light metal, on 6 November, and nine days later the first was ready, with numbers 2 and 3 all but ready, and bomb No. 1 was sent to Messrs. Vickers for installation trials on 24 November.[2]

In parallel with body manufacture, R.A.E. went ahead with the production of parachute trays (containers) and ballistic tails. Immediate arrangements in anticipation of production had been made by D.Arm.D. with the Ordnance Board for trials : static detonation, proof of body strength, testing of parachute and live drop.

Parachute manufacture did not proceed without difficulty. Little knowledge was available about the best material to use for a bomb of 4,000 lb. weight, although useful lessons were learned from an examination of the materials used by the Germans for their mine parachutes. A rayon material 'Penasco' (a production similar to the German material) and cotton fabric covers were tried, and specimen parachutes of each were produced.

By the beginning of December two empty bomb bodies had gone to Woolwich for filling ; bakelite tubes for exploders were ready ; six parachutes had been manufactured, and the conversion of the Wellington by Messrs. Vickers was approaching completion.[3]

The first installation trial took place at Weybridge on 9 December, and was not entirely successful. No bomb trolley capable of carrying such a bomb was then available, and the bomb had to be manœuvred under the aircraft on a skate specially constructed at R.A.E. After a good deal of manhandling the bomb was eventually hoisted by two Handley Page winches, and attached to the release slip. It was then found that the front winch cable could not be disconnected, and it was obvious that a good deal of modification both to aircraft and loading devices was needed.

By the middle of February 1941 five bombs had been dropped by A. & A.E.E. Two inert filled bombs from 2,000 feet oscillated badly : an increase in the diameter of the parachute from 5 feet 6 inches to 7 feet 6 inches made matters

[1] No. 54. *See* Chapter 15.
[2] To design No. D.D. (L) 11555B. M.A.P. File S.B. 11217/1.
[3] M.A.P. File S.B. 11217/1.

worse, and the bomb struck tail first and broke up. A drop with the smaller parachute from 6,000 feet again showed no improvement, but a second H.E. filled bomb dropped from this height detonated in soft clay, and gave a crater similar to that of the 1,900 lb. G.P. bomb. These initial trials were thus not encouraging, and showed that the bomb was far from suitable as a service weapon.

On 20, 24 and 28 February 1941 detonation trials of both the 2,000 and 4,000 lb. H.C. bombs were completed at Shoeburyness.[1] Blast pressures were measured. By this time there was, however, such an urgency for the bomb that some experimental models were offered to Bomber Command for operational use, and preliminary orders for 1,000 bombs were placed.

Meanwhile, efforts at A. & A.E.E. to improve ballistics met with some success in trials on 14 February. A 'nose spoiler' was fitted, a band round the nose projecting beyond the body and forming a hollow. This nose attachment henceforth formed a standard fitting for all H.C. bombs.

By the beginning of March bombs from the experimental order, and equipment, began to be available for operational use. R.A.F. Station, Marham, in Bomber Command, was chosen as the testing place. Bombs, parachute assemblies, 'nose spoilers' and hoisting winches were all assembled, and two Wellingtons, modified for the bomb, were ready by 8 March 1941—unfortunately without release slips. Special aiming instructions were prepared and issued to the station showing a range of false settings for the course-setting sight. Bombs in any case could only be dropped down wind if any attempt at aim was to be possible.

The initial loading trials at Marham on 10 March revealed an undue number of difficulties. The bomb had still to be transported to the aircraft on a 'skate' as no trolley was available. This primitive apparatus, a low transporting platform on castors, proved inadequate and broke down after two journeys from the bomb dump to the aircraft.[2] No arrangement had been made for attaching the parachute opening cord; the parachute assembly proved difficult to fit, and the hoisting arrangements were primitive and unsatisfactory; and the bomb carrier, after the bomb was in position, was inaccessible.[3] Two days later, two bombs fell off aircraft engaged in flight trials. As a result, Messrs. Vickers were obliged to modify the carrier and release arrangements extensively. Further trials of this kind, unsuitable for an operational station, were completed at A. & A.E.E.

Fortunately by 16 March other trials with a drum tail had been completed on the bombing range at Ashley Walk. Two bombs were dropped and fell steadily. One of these was filled H.E. and detonated successfully; the other, inert filled, fell on gravel and clay and did not break up, indicating that the complications of a parachute were probably quite unnecessary. In August 1941 the Air Staff came to this conclusion, and from that date parachutes were no longer used. So far, although the Air Staff had asked for 1,000 of these bombs, the initial experimental order by D.Arm.D. for 100 was still incomplete, and, as in the case of the 2,000 lb. H.C. bomb, this experimental order was followed by a second for a further hundred bombs, so that there should be no break

[1] O.B. Proc. Q. 233/41.
[2] M.A.P. File S.B. 11217/2.
[3] Mr. Wallis, Vickers' Chief Designer, writing to D.Arm.D. on this incident, remarked, 'I was horrified when I saw how completely inaccessible the crutches were'.

between its completion and the start of the production order. In April the initial production order for 1,000 was followed by an order for 360 bombs monthly. During the same month, photographic interpretation showed that the blast effect damage caused by two 4,000 lb. H.C. bombs in a raid on Emden on 5 August was severe.

By the end of May 1941 a number of 4,000 lb. bombs had been used by Bomber Command in operations, and in every case instantaneous fuzing had been used. In that month, D.Arm.D. called a meeting to discuss the delay requirement, with representatives from the Air Staff, the Ordnance Board and Design Department.[1] It was then confirmed that although direct action (instantaneous) fuzing was the main requirement, delay, one to two minutes and one to thirty minutes, was still required in a limited number of bombs for low level attacks on canals.

Trials, to test delay arrangements, took place during June and July 1941. An adaptation of the No. 37 (long delay) pistol was used, fitted in the side and armed by a length of cord coiled round a pulley on the arming spindle of the pistol, and secured to the aircraft.[2] Delay of 30 minutes was obtained by acetone and celluloid, and of 90 seconds by acid on metal. Both 2,000 lb. and 4,000 lb. bombs were used, all with parachutes from 2,000 feet. The 4,000 lb. bombs cartwheeled: the base plates broke away on impact, and most of the explosive content was lost. This is described in the Report as 'unsatisfactory'.

The rather primitive system of rotating the arming spindle by an unwinding cord was a failure: and as the bombs tended to finish their flight with the side fuzes downwards, the acid in the 90 second delay pistol did not run into contact with the metal. The celluloid-acetone system for the longer delay was rather more hopeful, as the celluloid could be dissolved by vapour as well as by liquid. The trial was continued on 13 July, by which time the base plates of the 4,000 lb. bombs had been strengthened, and the cord of the pistol replaced by copper wire. Only 30 minute delay pistols were used, two in each bomb. Four bombs were released from 300 feet, and although all bounced and one cartwheeled seven of the eight pistols armed correctly and gave delays of 25 to 51 minutes. This trial was followed by a live drop (fuzed 30 minutes) over Lyme Bay on 30 July, from 650 feet into water approximately 20 feet deep, and complete detonation occurred after 23½ minutes.

The 4,000 lb. H.C. bomb was formally introduced into the service in January 1942, as Mark I, by which time it had been successfully used in operations.[3] By September 1941, 226 had been dropped with no proved failures. Reports on damage showed that the bomb was satisfactory and 'created a tremendous impression on the population'.[4] Bombs on Emden, Berlin, Kiel, Wilhelmshaven, Cologne, Hamburg, Essen and Norderney all caused extensive damage. This question of damage will be further discussed when the remaining marks of the 4,000 lb. bomb have been described.

Manufacture of the bomb and its parts presented few difficulties, probably because the design was one of extreme simplicity particularly after the disappearance of the parachute. It is worth mentioning that during a visit

[1] M.A.P. File S.B. 11217/3.
[2] *See* No. 47 Pistol, Chapter 16.
[3] M.A.P. File S.B. 11217.
[4] A.M.W.15, Nos. 84 and 87. M.A.P. File S.B. 11217/4.

to England by General Arnold, of the American Army, he was so impressed by the bomb that on his return to U.S.A. he requested the American Ordnance Department to produce a 4,000 lb. bomb of similar design. Full particulars of the British bomb were cabled to the British Air Commission at Washington.[1]

The 8,000 lb. H.C. bomb

The design of a high capacity bomb of 8,000 lb. presented several new and interesting problems in the development of a suitable case, and its handling, carriage and release, and in the effective detonation of a large mass of explosive. In this particular bomb, handling and filling were to some extent simplified by the construction of the bomb in sections ; a new and interesting experiment which was later still further developed in the design of the 12,000 lb. H.C. bomb. The problem of detonation was not so simple and was eventually solved by a change in the composition of the main charge.

With the advent of large bombs, their carriage in aircraft became a major problem. As long as the weight of a bomb was confined to 500 lb., a state of affairs which had continued right up to the outbreak of war, the problem of transport, and attachment to aircraft presented few problems. A place could usually be found somewhere in the aircraft for small bombs and elementary methods of hoisting them into position were sufficient. Consequently little progress in the development of means of handling, transporting, and hoisting very large bombs had been made, and it was necessary to give far more consideration in the design of aircraft, to the accommodation of the larger and larger bombs which made their appearance between 1940 and 1942.

All these questions had arisen with the introduction of the 4,000 lb. H.C. bomb, but with the doubling of this size they threatened to become really serious. Originally, in January 1941, the 8,000 lb. bomb was intended for carriage in a modified troop-carrying glider, as part of a special programme for the development of such aircraft, the final stages of which were the production of a pilotless bomb-carrying glider and finally a ' winged bomb '. For this type of carrier, a diameter of 48 inches was allowable, and sketch designs for a bomb of this size were prepared by C.S.D.

The Air Staff requirements for the new bomb were forwarded by D.Arm.D. to the Ordnance Board in March 1941, and were as follows :—

(*a*) To weigh approximately 4 tons and to give maximum blast effect over the greatest possible area.

(*b*) Required primarily for instantaneous fuzing with a drogue and ballistic tail, but also for delay action with a parachute. In the first instance however, direct action alone would be acceptable to avoid delay in production.

(*c*) To have sufficient stability to give reasonable aiming accuracy, and angle of impact to ensure satisfactory instantaneous detonation from heights upward of 5,000 feet. When fitted with a parachute to be strong enough on impact with hard targets to give complete detonation from any height between 500 and 20,000 feet.

(*d*) Carriage in the type of aircraft previously mentioned.

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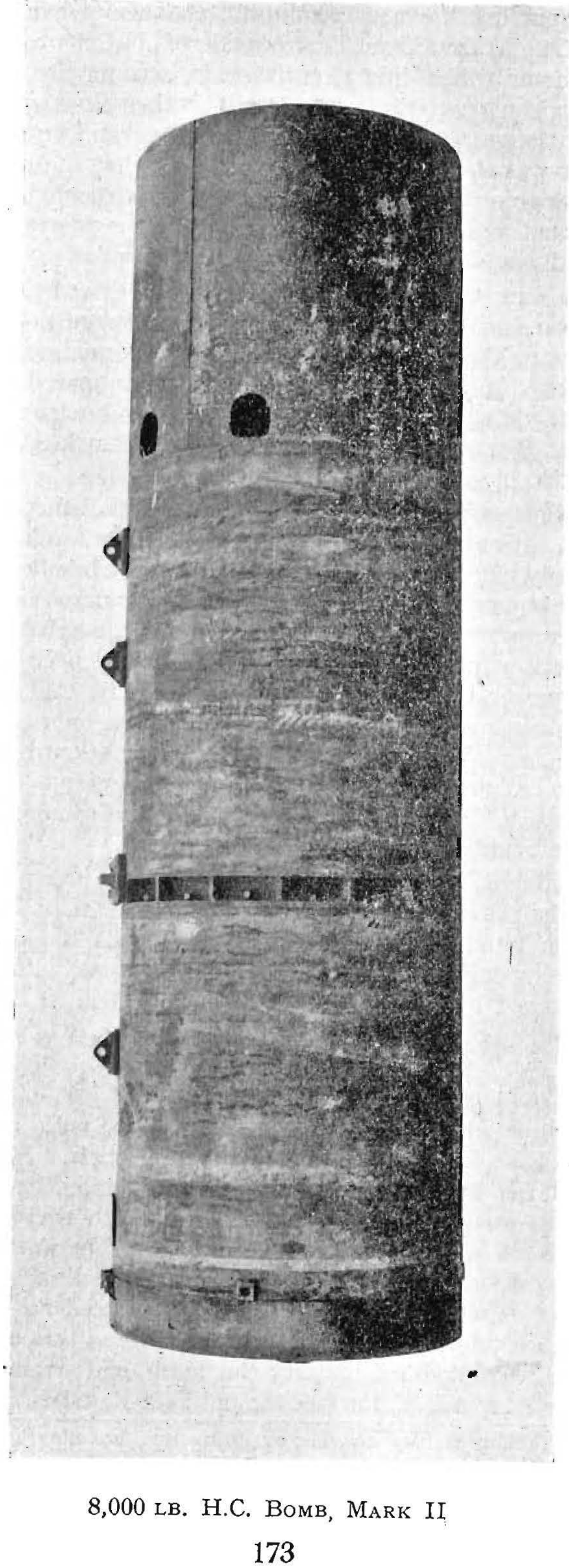
[1] B.A.C.W. Cable. Briny 5505, 21 May 1941. M.A.P. File S.B. 11217.



8,000 lb. H.C. Bomb, Mark II

The Minister of Aircraft Production asked for an investigation into the possibilities of putting the new bomb into the heavy bombers then under development. The Warwick was first considered, but it was evident that the maximum diameter which this aircraft could accommodate was 30 inches. To keep the weight up to 8,000 lb., the bomb, as then envisaged, would have to be increased in length, and manufacturing, filling and transport difficulties would arise. It was therefore proposed by C.S.D. that the bomb be made in sections, each weighing approximately 2,000 lb., which could be bolted together. This, it was argued, would simplify handling, up to the point where the sections were joined, and would make manufacture and filling easier.[1]

This idea of a composite bomb was new and untried, and the difficulties were obvious; simultaneous detonation in particular appeared doubtful even if the air spaces between the sections were reduced to a minimum. The greatest disadvantage of such a bomb was its extreme length compared with its diameter. C.S.R.D. had calculated that any bomb the ratio of whose length to its diameter was greater than 3, would be inefficient, and the 30 inch 8,000 lb. bomb had a ratio of considerably in excess of that figure.

There were thus two projects afoot: a 48 inch diameter efficient bomb which could be carried in a glider, but not in a bomber, and a 30 inch bomb of doubtful efficiency, which would fit the modern heavy bomber. Fortunately it came to light that an error had been made in the examination of the Warwick and that the aircraft would accommodate a 38 inch bomb. Such a diameter gave a more satisfactory L/D ratio, and the obvious decision was made by D.Arm.D. in consultation with D.O.R. and C.S.R.D. that a 38 inch bomb would satisfactorily meet both requirements. Work on a 48 and a 30 inch bomb was therefore abandoned, and the Ordnance Board was asked to go ahead with the design of a bomb of the new dimensions. In the meantime R.A.E. took steps to design a suitable parachute, and commenced experiments with German parachutes removed from mines.[2]

By the beginning of June C.S.D. had completed preliminary designs for the new bomb.[3] The principle of making the bomb in sections had been retained but the division into four 2,000 lb. parts had been thought extravagantly small, and the new design showed two 4,000 lb. sections, with a tail unit. The sections were joined by means of flanged rings welded to the body, through which bolts could be secured. Arrangements were at once made for the manufacture of two hundred bombs; manufacture was temporarily to cease at twelve until preliminary trials should have verified the feasibility of the scheme.

By August, three bombs had been completed, filled with inert material, and sent to A. & A.E.E. for handling and installation trials. Two further bombs were filled with H.E. and sent to Shoeburyness for detonation trials.[4] Another inert filled bomb was sent to a Maintenance Unit so that experience in the handling of such a large bomb could be obtained. The initial handling trials at A. & A.E.E. early in September revealed various small manufacturing faults, due to the speed at which the contractor had produced the first models, and some difficulties in joining the sections, but none was serious. By that time a Lancaster had been modified to carry the bomb, and arrangements made for it to be flown to A. & A.E.E. for loading and ballistic trials.

[1] There was no filling factory capable of lifting and handling more than 4,000 lb.
[2] M.A.P. File C.S.B. 15204.
[3] D.D.(L) 12484.
[4] M.A.P. File C.S.B. 15204/2.

During October the static detonation trials were completed at Shoeburyness in collaboration with the Director of the Road Research Laboratory, who issued a separate report. The trials were of the greatest importance as they revealed a very serious deficiency in the blast effect of the bomb compared with the 4,000 lb. size. This deficiency occurred in what was described as the 'pressure pulse duration'; blast pressure and fragmentation were reasonably satisfactory, but although the former came up to expectation in intensity it fell short of it by 50 per cent. in duration. Two bombs were detonated and neither in this respect was as effective as a single 4,000 lb. bomb. Trials with separate sections of the 8,000 lb. bomb gave less satisfactory results than the single 4,000 bomb. The filling in each case was Amatol.

The Shoeburyness experiments were confirmed to some extent by visual and photographic observations which had been made at A. & A.E.E. where a live bomb had been dropped from 6,000 feet. The result was by no means 'spectacular'. Blast and fragment damage was confined to two angles, diametrically opposed, of about 45 degrees. The trial had however little scientific value as no instrumental measurements were made. Various theories were proposed by C.S.R.D. to account for the failure: the position of the origin of detonation in the nose of the bomb, the thickness of the case, the type of explosive, the sectional construction.[1] Trials to confirm these were arranged under the supervision of Dr. Rotter of C.S.R.D.'s department, with the collaboration of the Design Department.

In December an important decision was made by the Air Staff that the 8,000 lb. bomb need not be provided with delay mechanism. This not only simplified manufacture in dispensing with special side pockets for delay fuzes, but also made the use of a parachute, with all its complications, unnecessary.

Meanwhile the investigations into the efficiency of the bomb went forward. Both a 4,000 and an 8,000 lb. bomb were specially filled R.D.X./T.N.T., and the superintendent of experiments at Shoebury made arrangements to test these, together with a bomb of new wall thickness, without delay. By the middle of January 1942 all trials had been completed. A bomb with central initiation showed no improvement: the bombs with special case thicknesses were, if anything, less satisfactory than the original. On the other hand, a bomb filled with R.D.X./T.N.T. gave the results which would be expected by comparison with the 4,000 lb. bomb. The Ordnance Board as a result, recommended, on 8 January 1942, that until a more satisfactory system of initiation of the Amatol could be found, the bomb, except for a few filled with R.D.X.—then too rare for general use—should be abandoned.

Meanwhile a newly appointed Committee had been formed on 30 December 1941, in the Ministry of Supply, known as the 'Static Detonation Committee', to study questions of this character.[2] The trouble with the bomb was indeed the main reason for the setting up of the Committee and its first recommendation, after considering all the facts, was the filling of the bomb with Amatol, 85 parts,

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[1] O.B. Proc. Q. 537/41.

[2] The Committee, under the Chairmanship of Dr. Guy, F.R.S., included representatives of the Ordnance Board and D.Arm.D. Its terms of reference were:—'To study the scientific and technical aspects of the technique of static detonation of bombs and shells: to interpret experimental results and consider their application to development'. O.B. Proc. 15947/42.

plus R.D.X./T.N.T. 15 parts. Trials with this filling at once gave satisfactory results, and the Committee concluded that such a filling was at least 90 per cent. as effective as a complete R.D.X./T.N.T. filling.[1]

The solution of this problem cannot be said to have been completely satisfactory ; it was in fact to some extent a recognition of defeat. It did, however, produce a large blast bomb at a time when speed of production was paramount.[2]

The Air Staff in April 1942 approved the introduction of the bomb into the service, and arrangements were made for the completion of the experimental order for two hundred with the new approved filling.[3] No major change in the design of the original bomb was found necessary for the change over from experimental to general production. A number of minor modifications were, however, introduced. The side exploder pockets were no longer required ; the attachment of the tail unit was simplified by reduction in the number of holding bolts. The bomb with these minor modifications was given the pattern number Mark I.

About the middle of 1942, however, a Mark II design was introduced. This differed from the original in two ways only : the joint rings used to bolt the two sections of the bomb together were built up of forged steel, whereas castings had been used in the Mark I bomb ; and some slight alterations to the filling of the central tube were made. The new fabricated joint ring[4] was designed and made by the manufacturers of the bomb on a suggestion by Deputy Director of Armament Production (D.D.Arm.P.), the object being to save the labour and expense of casting, and was put to a very severe test,[5] in the presence of an A.I.D. Inspector, to which it stood up perfectly. By the end of August, the Mark II bomb was approved for service use, and the first 8,000 lb. bombs made on a general production order were of that design.

Although by the end of 1942 twenty-eight 8,000 lb. H.C. bombs had been dropped by Bomber Command on enemy occupied targets, no ballistic trials of the bomb had been made and dropping was therefore largely haphazard. The position was the same for the 4,000 lb. bomb, and at the beginning of December 1943, Bomber Command asked for an accurate determination of the terminal velocity of both bombs. Arrangements were accordingly made with the contractors in December for twelve bombs of each size to be filled accurately with inert material and for the C. of G. to be marked on each ; the exact weight of each bomb was also required. The trials were concluded by April 1944 ; eleven bombs were released from 10,000 feet and one from 4,000 feet at an air speed of 200 miles per hour. All fell consistently with slight oscillation at first, except the bomb from 4,000 feet, which, at 1,000 feet turned into a horizontal position and struck the ground in that attitude. It was concluded, in spite of this, that the bomb was ballistically consistent, with a terminal velocity of 910 feet per second.[6]

The development of the 8,000 lb. H.C. bomb presented no particular difficulty and proceeded with no undue delays, except for the unfortunate failure of the standard amatol filling. Nor did the novel method of construction, applicable

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[1] M.A.P. File C.S.B. 15204/2.

[2] Appendix No. 5 gives a summary of the various detonation trials which led to the final decisions.

[3] M.A.P. File C.S.B. 15204/2 and O.B. Proc. Q. 571/42.

[4] M.A.P. File C.S.B. 15204/3.

[5] A load of 308 ton/inch for five minutes.

[6] M.A.P. File C.S.B. 15204/4.

only to a cylindrical bomb, create any abnormal difficulty either in manufacture or detonation, while it undoubtedly simplified filling and handling. The method was successfully repeated in the design of the 12,000 lb. H.C. bomb.

Some mention must be made of carrying and loading problems, which were inevitable with the introduction of a bomb of this size. It has been already stated that the original intention was to carry the bomb in a glider, and its dimensions were based on this intention. These, however, prevented the bomb from being stowed in any of the heavy bombers then under development—Warwick, Halifax and Lancaster—and the diameter was therefore reduced to 38 inches. The glider project did not materialise and the Warwick aircraft was not developed. Arrangements had therefore to be made for accommodation in the Halifax and Lancaster. Owing to the divided structure of its bomb compartment, the Stirling could not be considered. This meant the provision of hoisting lugs in the correct position on the bomb, hoisting winches, either power or hand driven, and special release slips.

The Lancaster had originally been designed to carry only one large (4,000 lb.) bomb in its bomb load, and in May 1941, because of the alterations necessary to enable carriage of the larger bomb, it was decided to forego this in the Lancaster. In September of that year, however, the Air Staff decided that the aircraft should be modified to carry the bomb as soon as possible without interfering with current production. Although Messrs. A. V. Roe, Ltd., soon re-designed the Lancaster—new bomb doors giving a fuselage bulge were necessary—the preparation of assembly jigs, tools, etc., and then the fitting into the production schedule was quite a different proposition; in fact, by May 1942 the most the firm could promise was one modification a week until the end of the year, when it would go into the assembly line proper.[1] Later it was discovered that the introduction of these doors interfered with the installation of certain radar equipment,[2] and, as this was regarded by Bomber Command to be of paramount importance, Air Staff decided in December to modify only 10 per cent. of Lancasters to take the 8,000 lb. bomb. By that time the firm had made extensive arrangements, and had ordered large quantities of material for the new doors. A further compromise was made, strengthened by the discovery that the radar equipment in question was not available in such large quantity as had been estimated, although the supply was rapidly improving.

The position in the Halifax was very similar, except that the modification to the bomb doors was not so extensive. In fact, it was at the outset unnecessary, as with some strengthening the aircraft could be flown with the doors slightly open. At the same time sets of modified doors were manufactured and an arrangement made that they should be fitted to aircraft on Stations. This proved to be impracticable except in very small numbers. In any case the fitting of H.2.S precluded the use of modified doors, and it was finally agreed with Bomber Command that this must take precedence, and that 8,000 lb. bombs could not therefore be carried.

The whole problem was simplified later with the introduction of new Marks of Lancaster and Halifax aircraft, but the situation has been very briefly outlined to show the difficulty of introducing new and unorthodox equipment whose

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[1] M.A.P. File S.B. 17908.
[2] H.2.S.

production had not been foreseen. As may be expected from the size of the bomb and the limited number of aircraft capable of carrying it, comparatively few 8,000 lb. bombs were released over enemy territory. The number rose from 28 in 1942 to 550 in 1944, falling to 119 in 1945. Altogether a total of 1,088 was expended.

The 4,000 lb. H.C. bomb, Mark II

In April 1941 D.Arm.D., at the request of the Air Staff, commenced an investigation as to the suitability of a new pattern 4,000 lb. bomb to be known as Mark II. Although the new design by C.S.O. embodied some manufacturing changes, such as the strengthening of the attachment and the end plate and tail, a major change whereby three nose pistols instead of one were provided, appears to have had little justification. The fitting of these involved a re-design of the nose, which became a flat dome instead of a truncated cone in the Mark I pattern. The tail unit remained unchanged and the side exploder pockets were retained, although up till that time the 4,000 lb. H.C. type had never been used for delay action. It was not until December of that year that the Air Staff finally decided that, with the exception of a few bombs held for special operations, delay fuzing in H.C. bombs was not needed.[1]

The production of the Mark II bomb calls for no special remark. The trial of dummies was completed on 16 May. Installation in a Wellington was satisfactory, although there were minor faults in the dimensions of the hoisting and suspension lugs. As a trial method of connecting up the pistols with the carrier fuzing mechanism, a flexible link was connected to the central pistol and to the single fuzing box ; shorter flexible links were connected to the outside pistols and the central link. This method proved satisfactory in a drop, although it could not be conceived as entirely satisfactory. The whole and rather extravagant reason of providing three pistols was to prevent any possible failure : but a failure of the single fuzing box on the carrier would have placed all three pistols out of action. Accordingly, A. and A.E.E. recommended the fitting of two additional fuzing boxes—a further complication.

The bomb dropped in a satisfactory manner with almost vertical impact when fitted with the nose attachment (spoiler) which had proved necessary in the Mark I bomb. A further trial on 31 May in which a bomb was dropped without the nose attachment from 4,000 feet, showed that it was completely unstable in this condition. Henceforth all Marks of H.C. bomb were fitted with this attachment. With some small modifications the new design was approved and production arranged in July 1941.

The 4,000 lb. H.C. bomb, Mark III

The Mark II bomb was quickly followed by a Mark III pattern, which, while retaining the three nose pistols, was without side exploder pockets. This was in accordance with the Air Staff decision made in December 1941 and recorded above, that delay action would not be required in any H.C. bomb. A proviso, however, was made in the case of the 4,000 lb. bomb only that, should this requirement be revived, bombs with side exploder pockets could be brought back into production in four to six weeks. The Mark III bomb embodied several other minor modifications, the chief of which was the provision of transit bases ; built up metal rings of greater diameter than the bomb, which

[1] M.A.P. File S.B. 17521/1.

could be attached at the nose and tail of the bomb by screws to protect the body and facilitate rolling.[1] These were in fact the successors of the hollow transit rings bolted to the 2,000 lb. bomb.

In May 1942 some doubt arose about the efficiency of the outer nose pistols. Air Staff, in spite of the contrary opinion of the Ordnance Board, had continued to insist on multiple nose pistols. During live trials at A. and A.E.E. parts of nose pistols which should have become detached in the air were found in craters. Wind tunnel trials were made at R.A.E. to investigate the problem, and these confirmed that while the central pistol armed in air speeds up to 165 feet per second, the side pistols did not, due to the direction of air flow near the periphery of the nose.[2] In this trial No. 27 pistols—the pistol regularly used in the bomb—were fitted. A similar trial with No. 32 fuzes—the anti-submarine bomb fuze—proved successful for all pistol positions. Suspicion thus rested on the No. 27 pistol rather than on the bomb, and no further action was taken by D.Arm.D. other than to promise that the point would be remembered in the design of future pistols.

In June 1942 a proposal was made that the 4,000 lb. bomb might be a suitable weapon for the attack of capital ships. For that purpose a short delay after impact was required and this could be provided by the No. 32 anti-submarine bomb fuze. It had already been shown that this fuze would arm satisfactorily during the R.A.E. nose pistol trials, and it was now necessary to discover what depth of detonation could be expected with a setting of 0·5 and 1·0 seconds.

This trial was entrusted to M.A.E.E. at Helensburgh. The attack of shipping must be accurate, and the best chance of a hit with a bomb of notably poor ballistics was to come down low. It was therefore necessary to know what the lowest safe height for such a bomb—fuzed instantaneously—would be (the No. 32 fuze had D.A. action on striking a hard surface). This investigation was to be undertaken by A. and A.E.E. in collaboration with C.S.R.D.

The trial of the bomb fitted with a No. 32 fuze was unsuccessful, the bomb failing to detonate. It was therefore decided to try a combination of fuzes in the nose of the bomb to give instantaneous detonation on a hard target or delay on water. For this purpose a three-part trial was arranged with bomb fuzing as follows :—

- (*a*) Outside exploder pockets plugged, centre pocket fitted No. 27 pistol (with sharp striker) and a 1-second delay detonator.
- (*b*) If (*a*) was satisfactory a second bomb with centre pockets plugged and outside pockets fitted standard No. 27 pistols and instantaneous detonators, to be dropped 'safe.'
- (*c*) A confirmatory trial with all three pockets fuzed as (*a*) and (*b*), the two outers fuzed 'safe.'

The trial was completed on 29 July 1942 in deep water in Lyme Bay and was unsuccessful, as even on water the No. 27 pistol operated although set 'safe.' It showed, however, that a 4,000 lb. H.C. bomb fitted with a sensitive nose pistol would detonate with delay, on water.

The trials to determine the lowest safe height for dropping the bomb were completed at Millersford on 5 and 6 July.[3] The general plan was to detonate a charge of Amatol on the ground as the aircraft flew over, and in the relative position at which a bomb would have struck the ground. As the area was

[1] O.B. Proc. Q. 405/42.
[2] M.A.P. File S.B. 17521/1.
[3] A special testing range used by C.S.R.D.

restricted, the full charge of 3,000 lb. corresponding to the 4,000 lb. bomb filling was not used. Instead, a charge of 1,850 lb. T.N.T. with 100 lb. C.E. was used and the results ' scaled up.' The pilot flew at various heights, getting gradually lower, until, in his opinion, any further descent would be dangerous. At 935 feet the crew were thrown out of their seats and the instruments ' considerably disturbed,' and this was judged to be the minimum safe height for that particular charge. C.S.R.D. calculated that for the full charge of 3,000 lb. Amatol the minimum safe height would be 1,200 feet, and this the Air Staff amended to 1,500 feet to be on the safe side.

The 4,000 lb. H.C. bomb, Mark IV

In October 1942 a Mark IV design was introduced. This differed from Mark III in that the stiffening beam which had been welded to the inside of the bomb to strengthen the hoisting and suspension lugs was omitted. The fitting of this beam had impeded production considerably. (Stressing trials on a bomb without the beam had been completed at R.A.E. in September.[1] Loads of up to 6,000 lb. were applied to the bomb on its carrier, in various directions, without undue deflection, and it was concluded that the bomb was safe without the beam, and contractors were immediately instructed by D.Arm.P. to leave out the superfluous beam as soon as they conveniently could. The bomb in its new form became Mark IV.

Two other interesting events in the history of the 4,000 lb. bomb occurred in 1944. The first was its use as a large incendiary bomb, with a filling of perspex-benzene gel, and is described in the chapter on Incendiary Bombs. The second was the investigation of safe dropping ; the bomb was at that time being carried in Mosquito aircraft and it was essential, with this aircraft, that the bomb could be jettisoned immediately in any flying failure. The pilot had thus no time to choose a dropping place where detonation would be harmless, and with the ordinary pistol the release of the bomb with the pistol set ' safe ' was no guarantee that the bomb would not detonate on impact.

A suggestion from Bomber Command in June 1944, that the bomb might be fitted with a parachute, which could be used in emergency only, was not found acceptable, and a solution was eventually reached by the use of a special pistol, No. 55. Trials at A. & A.E.E. with inert filled bombs and live detonators were completed in July from 3,000 feet and proved successful.[2]

Two further marks of the 4,000 lb. H.C. bomb were introduced, Marks V and VI. These were of American manufacture and were similar to the British Mark IV bomb, except for the fitting of American suspension lugs.

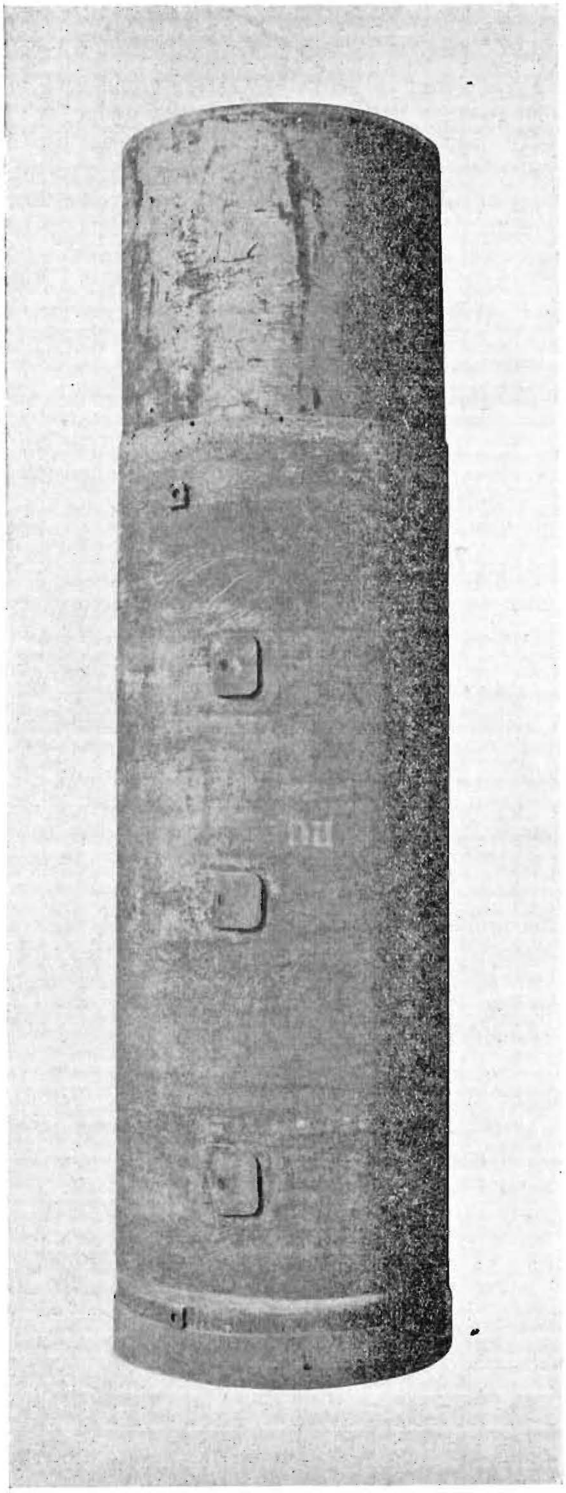
Operational use

Nearly sixty-eight thousand 4,000 lb. H.C. bombs were released over enemy territory during the years 1941 to 1945. The figures rose from 402 in 1941 to 2,979 in 1942 ; 23,135 were released in 1943 and a similar quantity in 1944. With the dropping of mixed loads, and the impossibility of ascertaining the effect of bombing, other than by photographs, the assessment of relative damage by one type of bomb or another is difficult. However, it was considered by the Ministry of Home Security that H.C. bombs were found to be about 1·4 times as effective weight for weight as M.C. bombs for causing structural damage.[3]

[1] M.A.P. File S.B. 17521/1.

[2] M.A.P. File S.B. 17521/2.

[3] M.O.H.S. Report R.E.N. 434—' Weapon analysis of British 4,000 and 8,000 H.C. bombs against industrial targets.'



4,000 LB. H.C. BOMB, MARK IV

The 12,000 lb. H.C. bomb

Mention has already been made of the Static Detonation Committee formed at the end of 1941 to study the effects of detonation under the Chairmanship of Dr. H. L. Guy, Chairman of the Institute of Mechanical Engineers. In July 1942 the Committee was approached by D.Arm.D. to give an opinion on the probable efficiency of a 12,000 lb. blast bomb, that is to say, an 8,000 lb. H.C. bomb with an additional 4,000 lb. section.[1]

The Committee gave their opinion as follows :—

> ' Having received the data available on the blast performance of the large H.C. bombs and the limitations on the carrying capacity of the aircraft concerned, the Committee conclude that by using a 12,000 lb. H.C. bomb a greater damage performance can be obtained than if the 8,000 lb. and 4,000 lb. are alone available ; provided that as complete detonation can be achieved in the 12,000 lb. bomb as with the 8,000 lb. bomb. If the Air Staff decide to proceed with the development of the 12,000 lb. bomb a static detonation test should be made by building up the three 4,000 lb. sections filled with Amatex (Amatol and R.D.X.).'

The proposed development of the bomb was discussed with D.O.R. and A.C.A.S.(T), and it was decided to proceed with the design, provided it could be carried in the Lancaster and provided the detonation trials were convincing. For the trials the Static Detonation Committee asked for three bomb cases, so that different explodering systems might be compared. Accordingly, the manufacturers of the 8,000 lb. bomb were instructed to prepare six additional 4,000 lb. rear sections, with some small modifications, and arrangements were made with Woolwich for two complete 12,000 lb. composite bombs to be filled with amatex, and two to be weighted with inert material. The initial loading test by the manufacturers of a complete weighted bomb was successful, the bomb showing no distortion or deflection when hung from its suspension lug and weighted.

Meanwhile the problem of carrying the bomb in the Lancaster had been examined by Messrs. A. V. Roe, and it was found that the bomb could be fitted to aircraft modified for the 8,000 lb. H.C. bomb, provided the length was reduced by five inches at the tail, although the final design of Lancaster would accommodate the bomb with its original length of 193 inches.

By January 1943 successful detonation trials had been completed at Shoeburyness, and arrangements were made for ballistic trials with inert bombs, and for a live dropping test at A. and A.E.E. These trials were also to include handling and loading, for which a special design of chain hoisting winch had been designed.

By May 1943 transporting, loading and dropping trials had been completed. For transporting, an ' E ' type bomb trolley was used, the sections being loaded separately and bolted together on the trolley. The loaded trolley was then towed over uneven ground, and the bomb finally installed in a Lancaster. These operations were successful, but preparation was a lengthy proceeding. The time for four men to load the trolley and bolt the sections together was two hours fifteen minutes. Transporting the bomb across rough ground

[1] M.A.P. File S.B. 39082.

required care as the ground clearance was only 4½ inches, and there was some end movement of the bomb. Loading to the aircraft took 35 minutes, and the bomb doors closed satisfactory. There were several minor difficulties during the loading operation but on the whole it was satisfactory.

The first ballistic tests were unfortunately not so successful and it was obvious that the short cylindrical tail was inadequate to give the bomb a steady consistent path. The problem of designing a more satisfactory tail was given to R.A.E. Models with cone shaped tails terminating in a tail drum (that is to say, the orthodox type of bomb tail) were dropped, and it was found that a 46 inch cone with a 15 inch drum gave stability but dangerously near the limit. No nose spoiler was used. Models with a 64 inch tail gave much more promising results, and although this length was suitable for the Lancaster it was unsuitable for any other available aircraft. These model trials were followed by full scale trials at A. and A.E.E. These proved that the shorter cone tail was unsatisfactory; further trials with 64 inch tails were, however, successful, and production with this tail was recommended.[1]

This was followed by a trial with a live bomb. On 25 September 1943 a bomb was released from a Lancaster at 10,000 feet on gravel-clay downland. The result was satisfactory: a crater 40 feet in diameter and 10 feet deep was formed, with fragment craters in an area of 150 feet diameter, but there was a suggestion that two detonation reports were heard, indicating that the rear section may have broken away. The pistol used in this trial was a No. 42, an orthodox type of D.A. impact pistol. There was, however, always some doubt in bombs of this size about whether impact break up of any part of the bomb might not diminish the chance of complete detonation. Accordingly, trials with another type of pistol (No. 44) of sensitive diaphragm design were necessary, first to prove that the pistol would help to give more positive detonation and, equally important, that built-up air pressure would not operate the pistol before impact.

Trials with the No. 44 pistol in October were inconclusive, owing to the lack of suitable recording apparatus, but it was evident that the bomb, dropped from 20,000 feet over the sea, detonated, if not on impact, at any rate very close to the surface of the water. It was therefore decided that this pistol might safely be used in the central position, while the standard No. 42 was fitted in the outside positions.

On 30 October 1943 D.Arm.D. asked the Air Staff for formal approval to introduce the 12,000 lb. H.C. bomb into the service, but this was not immediately given. In a Report on detonation by A. and A.E.E. dated 9 October some doubt, it may be remembered, was raised about whether all sections of the bomb detonated simultaneously. The Air Staff were therefore not satisfied that the bomb was reliable enough to justify general production, although by that time some thirty bombs had been released by Bomber Command, from the original development order. Air Staff's final approval therefore depended on further detonation trials but by the middle of December D.Arm.D. recommended a provisional order for fifty bombs, to meet the immediate requirements of Bomber Command, until the trials should be completed.

[1] M.A.P. File S.B. 39082.

The reluctance of the Air Staff to give approval for full production gave rise to a certain amount of confusion.[1] The position was that Bomber Command were urgently asking for twenty-four bombs for a special operation. D.O.R. replied saying that the bomb was still under some suspicion with its original filling of Amatex, but that number would be filled specially with Torpex to meet the Command's immediate requirement. If as a result of further trials it could be shown that this filling was satisfactory and would be three times as effective as the 4,000 lb. bomb, the Command was then invited to submit their requirements through the Bomb Provisioning Committee. Air Staff approval was limited to this number.[2] As a result the Command asked M.A.P. for six hundred bombs, and arrangements were in hand to produce these. M.A.P. were thus in a dilemma : Air Staff had not approved the bomb, and would not do so until the best filling was decided on : the Command were asking for bombs, and M.A.P. were producing them.

The staging of convincing trials proved to be a prolonged business, and in February 1944 D.Arm.D. wrote that, owing to the difficulty in getting pressure recording apparatus, it was unlikely that the trials could be completed within the next twelve months. There was, however, by that time considerable evidence of the effects of the bomb, and an interesting Report was prepared by the Ministry of Home Security on the assessment of damage by five 12,000 lb. bombs dropped at Agage. The results compared well with those theoretically expected, for example beach mines were detonated by the bomb up to a distance of 230 feet.

The predicted distance for such a bomb being 220 feet, D.Arm.D. considered that the evidence in the Report showed that detonation was complete—a point which was never fully established in development trials, and that the bomb was superior, in area of demolition, to three 4,000 lb. bombs of similar type.[3] This information, as well as that from other similar Reports, led to the approval of the bomb in March 1944.

Limited use of the bomb by Bomber Command continued throughout 1944 when sixty-seven were dropped and 1945 when eighty-two were dropped. The labour and time involved in loading up these bombs, the limitation of other loads which was involved, and the use of only one type of aircraft all made it necessary to reserve them for special precision targets, as may be gathered from the fact that a total of one hundred and eighty-six only was dropped during the war, on operations. Apart from preparation and loading, the use of the bomb presented no special difficulty.

Late in 1944, with the attack of Japanese occupied harbours in view, the Air Staff asked for an investigation into the effect of a 12,000 lb. H.C. bomb with a short delay fuze, dropped in water.[4] The trials were given to M.A.E.E. Helensburgh and to A. & A.E.E., the task of the former establishment being to investigate a means of measuring detonation by observing and analysing the ' dome ' created by under-water detonation. It had been observed that the first effect of such a detonation was the creation of a solid dome of water,

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[1] A.M. File C.S. 15995.
[2] A.M. File S. 96290.
[3] 12,000 sq. yds. ; the area for a 4,000 lb. H.C. bomb was 3,200 sq. yds.
[4] A.M. File C.S. 9769 and M.A.P. File S.B. 39082/2.

quickly followed by a violent eruption of the surface. The height of this preliminary dome was regarded as a measure of the violence of detonation. M.A.E.E. were satisfied that this method was possible and arranged experiments with delays of 0·05 and 0·1 second, which, from 20,000 feet, were calculated to give detonation at 35 to 55 feet.

Dropping trials were organised by A. & A.E.E., fast running cinematograph cameras being used to record results. The trials took place on 19 and 28 October 1944 in Lyme Bay, two bombs being dropped with 0·05 second and one with 0·14 second delay. The resulting film records were analysed by M.A.E.E. and by the Admiralty. They indicated that a cavity was caused by the passage of the bomb through the water which reduced the detonation shock wave to insignificance. There was evidence too that the bombs broke up near the surface and that detonation was incomplete. In the opinion of the Admiralty and M.A.E.E., therefore, the bomb was unsuitable for attack of harbours.

The 4,000 lb. H.C. bomb with increased charge/weight ratio

In March 1944 the Static Detonation Committee investigated a proposal to increase the blast performance of the 4,000 lb. H.C. bomb by using a very thin steel or aluminium case, and their reports were very favourable.[1] In the matter of weight saving and increased performance it was estimated that the two alternatives would compare with the standard $\frac{5}{16}$ inch case as follows :—

	Weight saved.	*Increase in area of demolition.*
(*a*) $\frac{1}{8}$ inch steel case	400–500 lb.	25 per cent.
(*b*) $\frac{5}{16}$ inch aluminium	600 lb.	30 per cent.

As a result of these estimates, development of both types was commenced in April but a decision regarding Air Staff requirements was deferred until static detonation and strength trials had been held. Suitable designs were prepared by C.E.A.D., that for the steel case estimated to weigh 450 lb. with a charge/weight ratio of 86 per cent., the aluminium case being 320 lb., charge/weight 89 per cent., compared with the normal bomb of 887 lb. and 74 per cent.[2] Experimental orders for twelve aluminium and nine steel cases were placed.

The doubtful factor in both types was the casing strength, and stringent trials were necessary. The testing equipment was held at R.A.E., at which establishment the first test bomb ($\frac{1}{8}$ inch steel) arrived by the end of June. The thin case was strengthened by a $\frac{5}{16}$ inch beam running the length of the bomb under the suspension lug and a central T-section ring, both welded inside the casing. This sample was tested on 6 July 1944, and the results showed that the casing was strong enough to comply with Lancaster flight factors.

Similar trials with the first aluminium casing were successful, but a further test under double loading (considered necessary on the cast portion) resulted in a fracture at the suspension lug, and re-design was necessary. Meanwhile

[1] A.M. File C.S. 22548.
[2] M.A.P. File S.B. 58981.

static detonation trials had been completed at Shoeburyness in September, and the results, analysed by the Static Detonation Committee, amply justified previous estimates as the following table shows :—[1]

	Weight, Empty Case.	Lb. Filling.	C/W Ratio, per cent.	Mean Damage Area Ratio.
Standard 4,000 lb. H.C. Bomb R.D.X./T.N.T.	880	3,000	78	100
*Standard 4,000 lb. H.C. Bomb, Minol 2 . .				114*
*Standard 4,000 lb. H.C. Bomb, Amatol 60/40.				59*
$\frac{1}{8}$ inch steel case, R.D.X./T.N.T.	476	3,091	87	124
$\frac{1}{8}$ inch steel case, Minol 2		3,099	87	140
$\frac{5}{16}$ inch aluminium, R.D.X./T.N.T. . .	322	3,050	90	145
$\frac{5}{16}$ inch aluminium, Minol 2		3,057	90	158

These figures were obtained using standard 4,000 lb. H.C. R.D.X./T.N.T. bombs as controls, the figures at * are mean results from previous trials. Such promise of improved performance led to an official Air Staff requirement early in October.[2]

The performance of the aluminium bomb was undoubtedly superior to that of the steel bomb—by some 12 to 16 per cent. Nevertheless, the prospects of production of the latter were at that time much more hopeful than of the former. Both were awaiting handling, rough usage and ballistic trials, but much more work in the development of the aluminium bomb was predicted : the cast parts had proved unsatisfactory and had to be replaced by others of different manufacture ; the position of the centre of gravity was likely to be different from that of the steel bomb, and special weighting was probably required. Both bombs were to have been tested for American suspension,[3] but D.Arm.R. ruled that American type lugs were not a requirement. This ruling brought a protest from D.Arm.D., who pointed out that by reciprocal arrangements made with U.S.A. in 1942 all bombs should have alternative American lugs, and the decision was amended : only bombs manufactured in America were to have twin lugs, and no further test would be necessary to assess the strength of the American lugs.

By November handling trials had been completed at No. 21 Maintenance Unit. They indicated that protective fittings would be required for the aluminium but not for the steel bomb. It was by that time fairly obvious that the development of a steel bomb would be completed much earlier than the aluminium type, and, in a review of the position by D.Arm.D. it was decided that with Air Staff approval the steel bomb should be adopted immediately for manufacture both in the United Kingdom and the U.S.A., and that the

[1] A.R.D. Explosives Report No. 121/44.
[2] M.A.P. File S.B. 58981.
[3] The American practice was to suspend bombs from two points.

development of the aluminium bomb should continue with a view to future introduction, which was unlikely to begin within the following six months. To these proposals D.Arm.R. agreed.[1]

From this point it will be convenient to follow the fortunes of the two types separately.

The 1/8 inch steel case

The development position of the thin steel case bomb, distinguished as Mark VII, in December 1944 was that deformation trials at R.A.E. had been satisfactory: rough handling trials at Fauld had been completed, and no major manufacturing difficulty had been met; on the other hand, no ballistic trials had been completed, and the design of a suitable tail cone was still outstanding. It therefore seemed clear, assuming that no ballistic difficulties would be met, to go ahead with arrangements for the change over from Mark IV, the service thick case bomb, to Mark VII, the thin steel case bomb.

The Equipment Branch, however, were reluctant to ask D.Arm.P. to organise an immediate change over, as the design of so many ancillary items was still outstanding. The production of Mark IV 4,000 lb. bombs was already insufficient to meet Bomber Command demands, and any break in production must be avoided. For instance the total production of Mark IV 4,000 lb. bombs in October and November from British and American sources had been eight thousand, whereas the expenditure had been twelve thousand.[2]

A meeting to discuss the change over took place at M.A.P. on 28 December 1944 with the President of the Air Armament Board in the Chair, and on 6 January 1945, D.Arm.P. was formally requested to arrange for the production of Mark IV bombs to be changed over to Mark VII.[3] Three weeks later, D.Arm.P. had received the necessary drawings from C.E.A.D. (late C.S.D.) and passed them to the Contractors, but pointed out that manufacture of the new bomb would not be so simple as that of the old.[4]

This opinion was confirmed by a report from A. & A.E.E. on the flying trials of an inert filled bomb. A bomb had been carried in a Lancaster for $8\frac{1}{2}$ hours, during which three landings were made.[5] Examination revealed dents at the carrier steady positions, accentuated by an air gap between the filling and the casing near these points. There were also some longitudinal distortion and it was recommended that interior strengthening plates should be fitted. C.E.A.D. was accordingly asked to amend the design, and at the same time to include several other manufacturing modifications which had been suggested by the manufacturing firms. The new design was in fact never put into production.

For some time there had been doubts about the strength of the bomb to withstand transit in goods trains, on ships and over rough roads. The U.S. authorities in fact declined to manufacture the bomb, as conditions of travel in America were stated to be much more severe than in Britain. The danger was said to be greater with a filling comprising aluminium such as Minol. A like view was taken by the Director of Filling Factories in the Ministry of Supply, who had urged stringent endurance and handling tests and had reported

[1] M.A.P. File S.B. 58981.
[2] A.M. File C.S. 22548.
[3] M.A.P. File Res. Arm. 6141.
[4] A.M. File C.S. 22549.
[5] A. & A.E.E. Report A.T.O. G.27, 26 January 1945.

his views to the Ordnance Board.[1] The Board asked D.Arm.D. for a full report on all strength trials completed. A list of all trials was prepared, and a Conference arranged by D.Arm.D. at which the Ordnance Board, the Director of Filling Factories and various other Departments were represented.[2] The stress trials completed by R.A.E. had been severe, flying trials mentioned above had revealed a weakness which could easily be remedied, stacking and handling trials with an empty bomb had revealed no serious weakness, and it appeared that the bomb could be accepted for use if it did not involve overseas shipment, for which protecting rings were recommended.

At a Conference held on 5 April 1945 C.S.A.R. pointed out that although deformation of such a bomb might not be dangerous, a pointed object driven through the case might be so. It was agreed therefore that protective fittings would be necessary for all bombs for transit from the Contractor to the Operational Unit. This was accepted by D.F.F., who pointed out, however, that more labour in handling would be involved. The Ordnance Board undertook to complete still further rough handling trials.

The discussion then went on to the Aluminium Bomb ; it will be remembered that originally it had seemed that the production of a steel bomb would be a comparatively simple matter, while a bomb in aluminium would be a lengthier project. It now appeared that this premise was likely to be false and in view of the fact that the aluminium bomb was more efficient, and that its production was not likely to be more than two or three months behind that of the steel bomb, the meeting decided to recommend that work on the latter should be abandoned. The recommendation was forwarded to D.Arm.R., and on 16 May it was agreed by Air Staff (D.B. Ops.) that work on the steel bomb might cease in favour of the aluminium bomb, now known as Mark VIII.[3]

The aluminium bomb, Mark VIII

Twelve prototype aluminium bombs had been constructed in June 1944 ; six were fired to test performance, and showed an improvement over the standard bomb of some 45 per cent.

By December C.E.A.D. had produced designs for the new bomb, and these were examined and discussed by representatives of all the manufacturing firms who made various proposals for their simplification. The revised designs were forwarded to the makers in that month and by the end of January 1945 C.E.A.D. had prepared notes on the assembly and testing of the prototype bombs made by each of the manufacturing firms.[4] The tests were principally concerned with airtightness. There were, however, several other details which, in a new bomb case medium, such as aluminium, required special tests. Some method of assessing the mechanical efficiency of a bomb produced by any particular maker was required : specifications to govern the acceptance of bombs had to be drawn up, the effects of age-hardening on the welds had to be examined.

By July A.I.D. had completed a series of tensile and bend tests, followed by micrographic and X-ray examination of bombs from each of the manufacturing

[1] Note G.D.F.F. to Sec. O.B., 10 February 1945.
[2] O.B. Proc. 29571/45.
[3] A.M. File C.S. 22548.
[4] M.A.P. File Res. Arm. 6130.

firms, and had submitted a series of comprehensive reports.[1] These all revealed some faults in welding, which in some instances was described as of low standard. It was, however, quite obvious that the technique of aluminium welding was far from established and that much research and investigation were still required. By the beginning of April C.E.A.D., in conjunction with the manufacturing firms, had produced a draft specification for welding procedure. As in fact the bomb had not gone into general production, and in view of the need for further research into welding methods no final specification was drawn up. The bomb was in fact still at the prototype stage at the end of the war.

The effects of large H.C. bombs against industrial buildings

The following is a summary of the effectiveness of 4,000 lb., 8,000 lb. and 12,000 lb. bombs against industrial buildings, being extracts from a Report by the Weapon Effectiveness Panel of the British Bombing Survey Unit.[2] The full report covers a study of the effects of German bombs on British industrial buildings and of British and American bombs on French and German industrial buildings. It relates to structural damage, that is damage to roof trusses, lattice girders and the like, sufficiently severe to cause the main structure to be taken down for repairs or abandoned as unsafe.

Data for the report are obtained from three main sources.[3] Ministry of Home Security Research and Experiments Department, British Bombing Research Mission and United States Strategic Bombing Survey (Physical Damage Division). Mention is made of two factors which make it exceedingly difficult to obtain satisfactory measurement of weapon effectiveness against industrial buildings, the first being variations in performance due to varying positions of bomb-hit. This has been borne in mind in the assessments by basing the results on the average of a large number of incidents over which the 'lucky' and 'unlucky' hits should balance. The second factor is the large variation in building construction, and, with this in mind, the report has sub-divided the types of buildings studied into five main classifications in an attempt to give a reasonably accurate assessment.

It was concluded that against such targets the Mean Area of Effectiveness (M.A.E.) of large H.C. bombs is about 0·67 acre/short ton, with insufficient data to show any significant variation of M.A.E. against single storey buildings of differing construction. Corresponding figures for 500 lb. and 1,000 lb. bombs are 0·38 and 0·49 against reinforced concrete single storey buildings, and 0·20 and 0·26 against all other types of single storey buildings. Large H.C. bombs are thus from 1·8 to 3·4 times and 1·4 to 2·6 times as effective per ton as 500 lb. and 1,000 lb. bombs respectively.

The data on multi-storey buildings are not so complete as for single-storey buildings, but they suggest there is little difference per ton between H.C. bombs, which cause damage chiefly by blast from near misses, and 500 lb. and 1,000 lb. bombs which cause damage by confined blast from direct hits. The M.A.E. for both types of bombs in structural damage to multi-storey or reinforced concrete framed buildings was about 0·10 acre/short ton. Whereas reinforced concrete construction behaves rather worse than other forms in single-storey industrial buildings, the reverse is the case with multi-storey framed construction.

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[1] A.I.D. Test Reports Nos. C. 20129, C. 20130, C. 20320, C. 22529 and C. 20019.

[2] B.B.S.U. Report D.G. Arm. W.E.S./3507.

[3] *See* Appendix 6 to D.G. Arm. W.E.S./3507.

CHAPTER 12

CLUSTER PROJECTILES

Scatter bombing

The possibility of bombing enemy aircraft in flight had been envisaged for many years, but no effort was made, in this country, to determine its efficacy. The Committee for the Scientific Survey of Air Defence, early in 1936, discussed the problems involved, the sighting problems were investigated and experimental work for the development and production of a small bomb was commenced.[1] The bomb was to detonate on impact, and had a fuze, incorporated in the design, for ensuring detonation before the bomb reached the ground. The possibility of using a large bomb was also discussed, together with methods of detonating such a bomb approximately in the horizontal plane containing the enemy aircraft. Experiments on an acoustical method were being conducted at the Air Defence Experimental Establishment (A.D.E.E.).

Early in 1937 the committee stated that no early application to the Royal Air Force could be expected, largely because the problem was more difficult than anticipated. The design of bomb, fuze, bomb installation and bomb-sighting were individually, solvable problems; the major complications arose from the choice of the type of aircraft to be used and from operational considerations. At that time the Royal Aircraft Establishment (R.A.E.) were considering a method of releasing a ' parcel ' of about one hundred 1 lb. bombs from an aircraft and of providing for arming and scatter when at a safe distance below the aircraft. The design of a suitable bomb of about 1 lb. in weight which would perforate a metal wing covering and also detonate inside, was being investigated.

Development proceeded during the next year and early in 1939 the scatter bomb—known as the ' S ' bomb—was in production. The bombs were made up into bundles of seventy-five—the bundle opened five or six seconds after release and the bombs were made live at the same time. The self-destruction fuze operated after approximately seventeen seconds and it was hoped to be able to alter the delay times without necessitating re-design after fuze.[2]

Development 1939–1945

During the early part of the Second World War, development of this ' parcel of bombs ' scheme continued, not with a view to bombing aircraft in flight, but to make an aimable weapon of the various types of explosives which had poor ballistics. Small bombs, such as small incendiary bombs, light case bombs, smoke bombs and numerous types of anti-personnel and fragmentation bombs were carried in the aircraft in the Small Bomb Container (S.B.C.). This was a metal box into which the bombs could be loaded and released from the aircraft when required. The S.B.C. remained on the aircraft, and could be re-filled for further use. When the number of 4 lb. incendiary bombs used in 1943 was 30 million, it will be realised how much labour was involved in reloading the S.B.C.s.

[1] *See* Chapter 19.

[2] Bombing Sub-Committee Paper No. 13 of March 1939.

The 'cluster projectile', essentially the same as the R.A.E. 'bundle of bombs', was developed as an improved method for the carriage of all types of small bombs. The bombs were made up into a single cluster using various metal components so that the cluster was approximately similar in shape to a round bomb of about the same weight. It was fitted with a fuze and tail, and was carried on a bomb carrier in the usual way. When released, it fell as a single bomb until, at some predetermined height above the ground, the operation of the fuze caused the release mechanism to operate, and the whole cluster disintegrated and the individual bombs fell freely.

The advantages of the cluster projectile over the S.B.C. were stated as :—

(*a*) Greater accuracy of aim was possible with the cluster which had a high terminal velocity, in most cases greater than that of the individual small bombs. This was of great importance when it was necessary to drop mixed loads, such as H.E. and incendiary, on the same target.

(*b*) Small bombs left the S.B.C. in a shower, and there was a danger that aircraft flying at a lower level may be hit. As a cluster, a large number of bombs were dropped as a single unit until well clear of other aircraft.

(*c*) Bombs from a cluster scattered over a smaller ground area than those dropped from the S.B.C. when released from the same height.

(*d*) Clusters could be carried externally on high speed fighter-bomber aircraft. This applied particularly to clusters of anti-personnel bombs which were released from Typhoon aircraft in dive-bombing attacks.

(*e*) The making up of clusters was carried out at the filling factory, therefore saving a great deal of time and effort on the operational station, where formerly the armament personnel carried out the filling and maintenance of the S.B.C.

Two types of clusters were developed. The first referred to as the 'bundled' type was later superseded by the 'nose ejection' type. Both were designed in 350 lb., 500 lb., and 1,000 lb. sizes so that it was possible to build up maximum loads on different types of aircraft.

The 'bundled' cluster

The small bombs were bound together to form a cluster which was approximately cylindrical in shape, the dimensions depended on numerous factors, such as shape, size and quantity of individual bombs; the available stowage space and the ballistic qualities of the finished product. A number of metal components were used to give rigidity and strength to the cluster and provided a means of disintegration at the pre-determined height above the ground. Essentially these components comprised the top and bottom beams, front and rear end plates, a number of thin metal straps and the release mechanism. The top beam carried the suspension lugs, crutch pads and part of the release mechanism the rest of which was located on the rear end plate. The bombs and cluster components were held together by a number of circumferential metal straps, attached to the top beam by the quick release mechanism, and provided with small springs which ensured that they flew clear on disintegration of the cluster. The straps were provided with tensioning bolts.

A bluff nose and a tail were normally fitted to each cluster. In addition some clusters were fitted with a number of fairings which improved the ballistics and gave some protection to the bombs inside. When required for external carriage on fighter-bombers, the bluff nose was easily removed and replaced by a streamlined nose fairing. A fuze of the barometric or pyrotechnic type was used to determine the height at which the cluster disintegrated. When released from the aircraft the cluster fell as a single bomb until the fuze functioned, the height at which this took place being determined by the initial setting of the barometric fuze or the type of capsule used in the pyrotechnic fuze. In both cases the explosion of the magazine depressed a piston in the fuze holder, which withdrew the release rod from the buckles on the straps, so allowing the latter to spring off and the whole cluster disintegrate. The small bombs then fell individually, their own fuzes arming on release or in flight, and functioning on impact.

The ' nose ejection ' cluster

This cluster was considered to be a distinct improvement on the bundled type. It was more robust, and could therefore be handled with greater ease, whilst at the same time provided greater protection to the bombs which it contained. Its ballistic properties were improved by being cleaner in design and the smaller number of components made manufacture and assembly easier. Also within certain limits, one set of components could accommodate different types of small bombs which gave greater measure of interchangeability than with the bundled type.

The nose ejection cluster consisted of a steel cylinder which was closed at one end by an end plate welded into position. This plate incorporated a fuze holder and a pocket for a burster charge. The small bombs were packed into this cylinder between two circular steel plates and a number of steel rods or channel members were provided to act as distance pieces between these plates. A heavy cast-iron nose closed the cylinder, being held in place by means of a number of shear bolts.

Normally the small bombs could be packed into the cylinder without the use of retaining straps, but when clustering the 4 lb. incendiary bomb, where it was necessary to ensure that the safety plungers were depressed, the bombs were bound together by a number of thin metal bands. A knife attachment was then provided to sever these bands as the cluster disintegrated. Suspension lugs were welded on to the cylinder to enable the cluster to be carried on either British or American aircraft. A tail unit was provided, which could be quickly attached when the burster charge and fuze had been inserted in the fuze pocket.

When released from the aircraft, the cluster fell as a single bomb until the fuze operated. The burster charge then exerted a force on the rear circular plate—referred to as the pressure plate—which was transmitted by the distance rods to the front plate and then to the nose cap. The nose cap retaining bolts were sheared and since the nose cap was free the contents were ejected at the the nose end, the thin metal band retaining the 4 lb. incendiary bombs being cut as the contents were ejected. As in the case of the bundled cluster, the individual bombs fell freely, their fuzes arming on release on in flight, and functioned on impact. The clustering programme was a large one ; towards the end of the war thirty-four classes of clusters were envisaged.

CHAPTER 13

THE WALLIS BOMBS

12,000 lb. ('TALLBOY')
22,000 lb. ('GRAND SLAM')

The original conception of large deep penetration bombs

Between July 1940 and March 1941 Mr. B. N. Wallis of Messrs. Vickers Armstrong Ltd. (Aircraft) wrote a paper which he called 'A Note on a Method of Attacking the Axis Powers'. This paper, comprising some 50 pages with a further 50 pages of Appendices, was the work of a mathematician, and, to quote the author, was compiled 'in view of the large number of objections to a bomb of this size which have been raised by many of the people to whom I have described the idea, it seemed to me essential that I should do enough work on the bomb side of the proposal either :—

(*a*) to convince myself that I had been mistaken in my original conception, or

(*b*) to show that the idea had sound foundations.'

The 'original conception' referred to was a very large bomb—of the order of ten tons, and a suitable long-range aircraft to carry it, as the answer to 'the terrible' stalemate of modern warfare.

At first he was only concerned with the design of a very large aircraft for such a bomb, then, writing to Air Marshal Tedder at the Ministry of Aircraft Production on 4 October 1940, the quoted passage regarding objections occurred, and the letter went on to report on progress then made with the design of a ten ton bomb, and the scope of his investigations into the matter. Briefly, he had consulted various authorities both in Industry and in Government departments on the following :—

(*a*) The design, manufacture, and filling of the bomb casing.

(*b*) The destructive power of bombs in general, and with particular reference to special targets.

(*c*) The ballistics of high altitude bombing.

Mr. Wallis and his helpers carried on with the investigation without further reference to the Air Ministry or M.A.P. until the work was completed and a copy of the paper sent to A.C.A.S. (TR) on 13 March 1941.[1]

Mr. Wallis' theory was founded on three axioms :—

(*a*) Modern warfare is entirely dependent on industry.

(*b*) Industry is dependent on adequate supplies of power.

(*c*) Power is dependent upon the availability of natural stores of energy such as coal, oil and water.

By logical argument, based on a mathematical foundation and substantiated by practical observation, Mr. Wallis was led to the conclusion that the destruction of the targets enumerated in his third axiom demanded a new technique

[1] This paper is a classic of its kind and a very brief précis of the main arguments is at Appendix No. 7.

in bomb attack ; involving two departures from the normal practice. These were, in short, the employment of far larger bombs than had hitherto been contemplated and the utilization of the pressure wave set up by the detonation in the surrounding medium to destroy the target, instead of relying on surface destruction by a direct hit.

As the great targets which demand attack were, fortunately, all situated on the earth, buried under the earth, or in intimate contact with water, Wallis could formulate his new theory of bombing :—

> ' To attack these targets successfully it is necessary to inject the largest possible charge to the greatest possible depth in the medium (earth or water) that surrounds or is in contact with the target.'

Careful and reasoned argument then led the author to the practical conclusion that a bomb of ten tons and with sound ballistic properties, released from 40,000 feet would fulfil his requirements. The word practical has been deliberately used for although no bomb of this weight had then been designed, nor had any aircraft capable of carrying it to this height, and with a range to reach targets in Germany, been produced or even contemplated, there was no practical reason why such a bomb and such an aircraft should not be constructed. In the outcome the bomb did indeed materialise but not the aircraft. The Wallis theory was never put into practice and although his earth shock bombs proved effective as ordinary bombs capable of moderate penetration into most materials, the eventual height limitation of 18,000 feet prevented their use in the specialised role for which they were designed.

Moreover, one of the specific targets in Mr. Wallis' catalogue was the modern gravity dam, such as is used for the conservation of vast water power in Germany, particularly the Möhne Dam, whose destruction in 1943 was to stir the world. Although this destruction was wrought not by the original ten ton bomb, but by a weapon specially designed for the purpose, the Wallis theory was equally applicable, and indeed a great part of Mr. Wallis' paper is devoted to the destruction of various forms of dam. In the result this paper also led to the development of bombs known as ' Tallboy ' and ' Grand Slam ' which were destined to play an all-important part in the destruction of U-boat shelters and concrete emplacements for the launching of flying bombs and rockets.

Mr. Wallis' paper was considered by a special Committee under the Chairmanship of Sir Henry Tizard, Scientific Adviser to the Chief of Air Staff. This Committee of scientists and representatives of both the Air Council and M.A.P. concluded that there was ' something in the idea ', and accepted the theory of deep penetration followed by earth shock as a disruptive of enormous power, as sound. The subject was referred to C.R.D. (Air Marshal Linnell) for consideration who in turn asked for opinions from D.S.R. (Dr. Pye). His considered view was that there was : ' no case on scientific grounds in favour of a bomb larger than could be carried on existing aeroplanes. Even if it cannot be established that a ten ton bomb would be less effective than an equal load of, say, two ton bombs, there is at any rate no case for embarking upon the large amount of effort involved in order to make possible a form of attack of which the effectiveness, on present estimates, will be less than that with weights of bombs which can be carried '. This opinion, allied to the fact there was no aircraft capable of carrying such a bomb, led to the recommendation by C.R.D.

to the Air Staff that no development of the 10 ton bomb should take place, and the project so far as the Air Ministry was concerned was for the time being, abandoned.

In 1943 the attack and destruction of certain large concrete targets became increasingly important. No effective bomb existed for this task and as a result Mr. Wallis' deep penetration theory came up for reconsideration in that year.

Tallboy and Grand-Slam. Development and production

Before taking up the story of how these bombs were eventually produced and used it is necessary to emphasise one or two facts concerning the ' deep penetration ' bombs generally :—

(*a*) Three sizes were produced : 22,000 lb., 12,000 lb. and 4,000 lb., but the smallest was only a functioning and ballistic trial model, it was never intended for operational use.

(*b*) Although the 12,000 lb. size preceded the 22,000 lb. bomb in use, it was not the forerunner in design of the larger bomb, but in fact a scaled-down version of it.

(*c*) The original ' deep penetration ' bomb in invention and design remained the 22,000 lb. or 10 ton bomb originally advocated by Mr. Wallis. The use of the 12,000 lb. size before the larger arose because of a special operational requirement in 1943 when there was still no aircraft capable of taking the 22,000 lb. bomb.

At a meeting of the Air Staff held at Air Ministry on 8 June 1943 to discuss certain operations, a request was made by the A.O.C. No. 5 Group, Bomber Command, that the possibilities of the deep penetration bomb suggested by Mr. Wallis should be investigated. Mr. Wallis—also present—agreed to produce a report on the estimated penetration and effect of the bomb if released from 22,000 feet, and the Director of Bomber Operations (D.B. Ops.) undertook to investigate the possibilities of the weapon on receipt of Mr. Wallis' report.[1]

One of the targets for future operations was the Rothensee Ship-Lift, a massive structure in Western Germany forming a vital junction between river and canal transport services. Mr. Wallis' report, sent to D.B. Ops. on 26 June 1943, gave an exposition of the possibilities of penetration bombing on such targets, and he suggested a 12,000 lb. bomb—probably because he knew there was no aircraft capable of carrying a larger size.[2] He added that Messrs. Vickers then had a casing for a 4,000 lb. bomb at Weybridge. D.B. Ops. felt that the chances of obtaining a hit or sufficiently near miss to obtain the effect estimated by Mr. Wallis were slight, but nevertheless thought there was justification for further examining the project, and he took the matter up with the Assistant Chief of Air Staff (T.R.) and the Ministry of Aircraft Production.

On 30 June Bomber Command informed Air Ministry (A.C.A.S. (Ops.)) that after consultation with Mr. Wallis they were of the opinion that neither the proposed bomb nor the heavy bombs then in service would produce a satisfactory result in an attack on the Rothensee Ship-Lift. The letter went on to describe the Command's version of a practical way of neutralising that target, chiefly by the use of special deep penetration bombs dropped from 22,000 feet and falling within an area of 195 yards by 140 yards of any one of the main

[1] A.M. File C.M.S. 80.
[2] *See* Appendix No. 8.

shafts carrying the lift mechanism. In support of these conclusions the Command requested immediate Air Staff authority for the design and production of such a bomb.

Following this request a meeting was held by D.B. Ops. on 1 July, at which it was agreed that Air Staff approval should be given for the production of twelve 4,000 lb. models for ballistic and detonation trials and the development of the 12,000 lb. bomb.[1] Mr. Wallis estimated that if adequate priority was given production of the latter would be achieved by the following September at the rate of some 40 bombs per week.

The official requirement for the models and sixty 12,000 lb bombs was given by A.C.A.S.(T.R.) on 18 July to the Controller of Research and Development M.A.P., and mentioned that the bombs were primarily required for the attack and destruction of the Ship-Lift target within the next two months or so, but would also be considered for other objectives later on.[2] The immediate result of this authority was an order from M.A.P. to Messrs. Vickers, Ltd., not only for the trial models but for one hundred 12,000 lb. and 22,000 lb. bombs. This decision was made by the Chief Executive M.A.P., Sir Wilfred Freeman, and had the support of the Minister, Sir Stafford Cripps, and the fact that it involved production of the larger bomb should be remembered later in this account. The code name 'Tallboy' was allotted as a preliminary for all sizes of bomb.[3]

By the end of July the opposing interests of Air Staff and M.A.P. for the two operational sizes of bomb was causing confusion. Messrs. Vickers, Ltd., were making the twelve models (known as Tallboy (S)), the English Steel Corporation, Sheffield, were engaged on production of the 22,000 lb. bomb (Tallboy (L)) already designed by Mr. Wallis, but design work only was being done on the 12,000 lb. bomb (Tallboy (M)). This was certainly not in accordance with Air Staff requirements, and the Deputy Director of Armament Development (Bombs) requested C.R.D. to obtain a ruling as to the priority for production of either of the two types of operational bomb. In the reference quoted he wrote, 'The Bomber Command requirement for a 12,000 lb. deep penetration bomb will very seriously affect the development and production of the 22,000 lb. bomb which has been agreed upon at Ministerial level but about which the Air Staff appear to know very little.' D.D.Arm.D.(B) went on to say that he had consulted Mr. Wallis about the Sheffield Steel Corporation producing both sizes of bomb, who gave the emphatic opinion that development of the one would seriously affect that of the other, and in fact the two could not be produced at the same time with the resources then available.

However, the matter of either or both types being produced was taken up between Air Staff and M.A.P., figures quoted by the latter on 2 September being as follows :—

- (*a*) Tallboy (M) only—a total of thirty-two bombs by the end of December 1943, and thereafter at the rate of nine per week.
- (*b*) Tallboy (L) only—as above.
- (*c*) Both types—sixteen of each by the same time and thereafter at the rate of four and a half per week.

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[1] A.M. File C.M.S. 80.
[2] A.M. File C. 26698.
[3] M. of S. File S.B. 50904.

The Deputy Chief of Air Staff considered the M.A.P. reports on production, and on 25 September he recommended to the Chief of Air Staff that there was no justification for proceeding with the larger bomb.[1] The reasons were briefly as follows :—

(a) To carry Tallboy (L) a specialised aircraft was required which would not be of use for other purposes as it would only have an operational range of about 140 miles. The aircraft ceiling was likely to be below 20,000 feet ; this would prevent full bomb penetration being obtained.

(b) It was proposed that the bomb should be used against the concrete emplacements in the Pas de Calais.[2] There was no precise information about such targets at this time, and in fact there was no evidence to suggest that ' Tallboy ' bombs of any sort were required for the attack of such targets.

(c) There was no other target likely to be within the range of a specialised aircraft which would require attack by such a bomb.

(d) As the scaled down model Tallboy (S) had not been tried, there was no practical information as to the results to be expected from Tallboy (M). This bomb could, however, be carried on a standard Lancaster without much modification, and should it be found effective it would be far more economical to use a large number of that size against the concrete emplacements mentioned.

(e) In view of the large production effort needed for ' Tallboy ' which could only be obtained at the expense of other urgent requirements it seemed logical to go for the (M) size, which might produce the result required, and then later, if the need arose, to order the larger bomb.

These recommendations were supported by C.A.S., who in turn received the approval of the Prime Minister, and the decision to stop work on Tallboy (L) was communicated to the Chief Executive M.A.P. on 30 September.[3] This shelving of the development of the large bomb proved to be only temporary, but until its re-introduction as ' Grand Slam ' this account will deal only with the progress made with Tallboy (M).

Development of Tallboy (M) to meet Air Staff requirements

While the policy of Tallboy (L) or (M) was being discussed, Sir Wilfred Freeman had been in touch with Sir Richard Fairey on the British Air Commission in America concerning the manufacture of Tallboy (M) in that country. The outcome was that early in September Sir Richard Fairey signalled that he had found production capacity at the rate of two per day.[4] Because of the known small facilities in this country the Chief Executive immediately placed an order for 100 and requested V.C.A.S. to obtain on high level all the priority the U.S.A. could possibly give for manufacture. This help was readily promised by General Arnold in the U.S.A. following a request by C.A.S. through General Eaker, Commanding the 8th U.S. Air Force in this country. On 23 October 1943 the order was increased to 125 bombs, and this too was accepted by the U.S.A. authorities on the same priority.

[1] A.M. File C. 26698.
[2] ' V ' Weapon Site.
[3] A.C.A.S.(T.R.) Folder B.4/4, 30 September 1943, and M. of S. File S.B. 50904.
[4] D.C.A.S. Folder R/4A, 14 September 1943, and 5 October 1943.

By the beginning of October 1943 the number of Tallboy (M) bombs on order was 325 ; this included the 125 from U.S.A.[1] and 200 in this country, the latter figures being that originally ordered by M.A.P. except that the contract for Tallboy (L) was cancelled and the production capacity thus released was turned over to the same quantity of the smaller bomb.

Meanwhile trials with 2 inch models supplied by Messrs. Vickers were being made by the Home Office Department of Scientific and Industrial Research. The first series was completed in August, the investigation being made to examine depth of penetration into natural chalk at a striking velocity of 1,100 feet per second, and the damage to the bomb. The ' bombs ' were of high tensile steel filled with napthalene to represent H.E. and were fired from a 2 inch mortar. The results showed that the maximum theoretical penetration to be expected from a 12,000 lb. bomb was 75 feet, and that little or no damage to the bomb case might be expected. In practice, of course, such a depth would not be achieved as the path of a bomb through earth or chalk is seldom a continuation of its air path—it may indeed have a large horizontal travel.

A second report was issued in October giving details of penetration into clay. It showed that a depth of 150 feet could in theory be expected for the actual bomb, with some less depth in practice, and again no serious damage to bomb cases was recorded.[2]

A third report appeared in March 1944 and described experiments for firing small scale models at slabs of concrete representing an actual thickness of 13 feet and 20 feet of both plain and reinforced concrete. Inert models perforated the 13 foot plain slab, but just failed to do so in the reinforced concrete ; neither of the 20 foot slabs were perforated, no damage resulted to cases. H.E. models were then detonated in the positions they had reached in the 20 foot slabs, the charge representing a full scale filling of 5,000 lb., and in this case perforated the plain concrete but only bulged the reinforced. From these experiments it was argued that if the model law could be assumed to hold over such a wide scale the 12,000 lb. Tallboy striking at 1,070 feet per second at normal angle would perforate a 13 foot slab of plain concrete, but not one of that thickness with top reinforcement : it would not perforate 20 feet of any concrete.

These model experiments, carried out with great care by the Department of Scientific and Industrial Research, although of great value could only serve to indicate what might be expected from the full size bomb ; more convincing information was to be expected from tests with the 4,000 lb. model. A limited number of this larger model (Tallboy (S)) were constructed in forged steel, although some later bombs were cast, so as to be truly representative of the full size bomb. It was the intention to use Tallboy (S) for installation and ballistic tests, for detonation trials, and for aiming practice.

Installation, flight, and preliminary dropping trials of the ' S ' bomb were completed by 8 November 1943 and were generally successful ; the dropping height was 5,000 feet and the bombs appeared to be stable. Early ballistic trials were unfortunately not so successful. An attempt was made on 8 November to release two bombs from 22,000 feet, but one fell after a delay of 5 seconds and the other after a delay of 5 minutes. The failures were attributed to icing, as conditions were severe and the release slips fully exposed. In later

[1] M. of S. File S.B. 50904.
[2] A.M. File C. 26698.

trials the slips were enclosed in canvas bags and great care taken to prevent any distortion during loading. Two further releases on 4 December were successful, but the recording camera failed. Much trouble was experienced with loading winches, and a complete new set was made by Messrs. Vickers. There was still no evidence other than visual to prove that the bomb was stable, and further releases were made from heights of 20,000 and 22,000 feet at Crichel Down Range which gave definite signs of instability. In one instance a tail was fractured in the air and was found at a distance of some 500 yards from the point of impact of the bomb. It was thus evident that the bomb in its present form would be useless for the accurate bombing which the Wallis theory demanded.[1]

On 28 January 1944 a meeting was held with D.D.Arm.D(B) in the chair and Mr. Wallis and various ballistic experts from M.A.P. in attendance. Examination of the bombs had shown surface irregularities which might have caused instability, and various suggested remedies were discussed, among them the addition of a drum tail, and off-setting the tail vanes to cause the bomb to spin. Wind tunnel tests with model bombs were arranged, and in February Mr. Wallis visited the Aerodynamics Department of the National Physical Laboratory and discussed the aerodynamics of Tallboy at length with members of that department. It was concluded that there was nothing wrong with the design of the bomb in its present form, and that the instability was probably due to its velocity which approached that of sound, a condition known to cause instability in projectiles. It was agreed that spinning was probably the most hopeful remedy, and that the most profitable experiment would be one made with a full size spinning bomb.[2]

Meanwhile a second investigation was set in train to discover if possible the reason why bombs released from 22,000 feet had broken on impact during the A. and A.E.E. dropping tests. Two theories to account for the failure were advanced at a second meeting at Messrs. Vickers Armstrong on 13 February, which was attended by Mr. Early, an explosives expert of the Research Department, Woolwich :—

(*a*) The effect of movement of the filling on impact or on any violent turning motion which might be imparted to the bomb during its travel through the earth ; and

(*b*) Faults in casting or heat treatment, or in the composition of the steel. It was noted that a forged bomb, dropped on the initial Orfordness trials, had not fractured.

Mr. Early suggested that a shock absorber or buffer of elastic material such as woodmeal and wax should be added to the filling at the base of the bomb ; the director of Machine Tools at the Ministry of Production proposed the casting of six bombs in Hykro[3] for tests comparative with the bomb already produced in pearlitic manganese steel. These castings were completed by the end of February and to hasten test results, Mr. Wallis arranged for the construction of a catapult for the trial of both modifications.

While experiments with the 'S' type were going on, development of the 'M' bomb had not been delayed. The 'S' trials had given some valuable ballistic information and had shown the necessity for spin to maintain stability,

[1] M. of S. File S.B. 50904/2.
[2] M. of S. File S.B. 50904/3.
[3] Three per cent. chrome molybdenum steel.

and for modification to the filling by the addition of a woodmeal shock absorber. Before commencing on the details of the type 'M' development, it is necessary to summarise the general position in the autumn of 1943 so far as the metallurgical problem was concerned.

The organisation behind the development of the bomb is of the greatest interest and may well serve as a model for the quick and efficient production of an important weapon. At such a time, the particular type and personality of individuals concerned not only with the actual production of the bomb, but also with the negotiations for its production between the Air Staff who require it, the Ministry of Aircraft Production, who are responsible for obtaining it, the designer, and the various firms who do the actual work, are of the greatest influence in furthering or delaying the progress of production. In the case of the Wallis bombs the 'team' behind its development and manufacture was happily chosen. There was, first of all, Sir Wilfred Freeman, Chief Executive of the Ministry of Aircraft Production, in a position to make decisions of far reaching importance without long and tedious negotiation with 'higher authority'; then the designer, Mr. Wallis, who had the untiring support of his chief, Sir Charles Craven, head of Vickers Armstrong, Ltd., and Mr. H. H. Burton, of the English Steel Corporation, a metallurgist of repute. In the Ministry of Aircraft Production were Mr. A. H. Hird, Director of Machine Tools, an official of Messrs. Vickers Armstrong who had been lent to the Ministry, and as D.D.Arm.D. (Bombs), Group Captain Wynter Morgan, an officer of wide armament experience, able not only to mix well with the various members of civilian firms involved, but also to express and maintain the Service point of view when necessary. With such a body of men, among whom decision could be taken as a result of a telephone call or a short meeting, without much of the slow-moving routine of government business, the development of these and other bombs of Wallis design was smooth and rapid. In the words of one member: 'It would be true to say that the whole negotiations were carried out much in the same way as would occur in industry among a group of individuals who trusted one another.'

Due largely to Sir Wilfred Freeman, Mr. Hird was given a free hand in the development of both Tallboy and later Grand Slam (the ten ton bomb), and with his own personal knowledge of industrial problems, and the easy accessibility of the designer (Wallis) and the metallurgical expert (Burton), he was able to carry through the whole project with little friction and few unnecessary formalities. The first problem which faced Mr. Hird was the lack of forging and machining facilities for a bomb of this size. There was in fact no capacity in the country at that time to produce such bombs in considerable numbers, without undue interference with other and often equally important war products. To produce the best bomb casing it was advisable to use the forging method known as 'piercing and drawing,' in which, briefly, a plunger is forced into the back of the ingot to produce the cavity in rough shape; the body is then drawn out either by pushing the bomb and plunger through a series of dies, or by hollow forging. Both these methods required large presses, and such presses for the first method did not even exist, and for the second were already fully employed. The forging method had thus to be abandoned and the bombs made as castings. This was only the beginning of manufacturing difficulties, the next being the heat treatment of the casting to give it the necessary hardness and toughness to withstand impact without fracture or collapse. The most satisfactory method of heat treatment was by oil hardening and tempering, but only one or two firms in the country had the necessary plant, which even then would have to be modified for bombs of such a size; this method had perforce to be abandoned in favour of the simpler process of air hardening and tempering.

The composition of the steel used was also a problem in itself. One of the firms engaged in the work was unable to make bomb castings in fully alloyed steel, but had much experience in the making of pearlitic manganese steel, which they used successfully for the manufacture of normal G.P. bombs. This was not, however, in the opinion of an informal committee, the best type of alloy steel to suffer the heat treatment available. This Committee, set up at the instigation of Mr. Hird, drew its members from Messrs. Firth Brown, the English Steel Corporation, Clyde Alloys, David Brown, and Hadfields. The last named firm was already fully occupied with Admiralty work, but in view of their great experience in the manufacture of projectiles, were invited, and consented, to take part in the discussions and give their advice. The Chairman of the Committee, which was in fact an informal body, was Mr. Burton, and it was he who from his long experience as a metallurgist, laid down the composition limits and methods of heat treatment for the guidance of the firms engaged in the work.

As has been explained, two types of steel were used: pearlitic manganese steel by Messrs. Firth Brown and 3 per cent. chrome molybdenum steel[1] by the remaining firms. The main difference between these steels was that the latter had a much higher yield point, and this reduced the tendency of the bomb to fold up on impact. Tests made by Mr. Wallis, by catapulting models against concrete targets showed the bomb with the high yield point to be superior against a resistant target. On the other hand the demand for output was so great that, to eliminate Messrs. Firth Brown's product would have meant an impossible sacrifice: accordingly both types of bomb continued to be manufactured throughout the war, although the chrome molybdenum type was in the majority.[2]

The position of Tallboy (M) casings by the end of 1943 was as follows:—

> Of the total order for 325 (200 U.K., 125 U.S.A.) about ten were completed in this country and were being machined ready for filling; production of the total being estimated for completion by May 1944, with a machining capacity for fifty per month.[3] In the U.S.A. manufacture was well in hand with an estimated rate of production of one finished machined casting per day.

Although finished bombs began to be available for filling in January 1944, unsuccessful trials with the (S) type model (described earlier in this chapter) had shown that fracture on impact was probable, and that an improvement in stability was necessary. The possible remedies for these troubles had been suggested at meetings held at the firm's works on 28 January and 13 February, and the problem was again discussed at a meeting convened by D.D.Arm.D. (B.) on 2 March 1944, at which it was explained that production filling could not proceed until the nature of the buffer had been decided upon. D.D.Arm.D. (B.)

[1] 'Hykro'.
[2] The foregoing unreferenced account of early development is derived from information supplied by Mr. Burton.
[3] M. of S. File S.B. 50904/3.

mentioned that operational use of Tallboy (M.) was envisaged for the following month and a programme of trials at the Aircraft and Armament Experimental Establishment was planned to commence as soon as filled bombs, including the suggested improvements, were ready.

By the end of March successful installation trials of a Tallboy 'M' in a Lancaster had been concluded, and a tentative set of loading instructions prepared by A. & A.E.E. Following this, an inert filled bomb with off-set fins was successfully released from 16,000 feet and although there was visual evidence of instability, this was not nearly so marked as that already observed in the 4,000 lb. model with non-spin fins. Although no time had been lost in the production of the bombs, the original hope of Bomber Command and the Air Staff, that some would be ready for operations in January had been unfulfilled, and seemed likely to remain so until the problem of stability had been solved. On the other hand to provide Bomber Command with any other than a stable bomb would have been folly; the larger the bomb, the greater the need for accuracy of bombing. It was therefore necessary to establish at once the success of the off-set fin, and to this end urgent trials were organised at the Ballistic range at Orfordness using five 'S' type bombs with fins set to impart a spin; to the exclusion of all other current ballistic work. By the middle of April, these trials had not been completed, trouble having been experienced in releasing the bombs from the aircraft. The need for the bomb in operations was then becoming imperative, and in view of the comparative success of the single full-scale bomb released from 16,000 feet at Crichel Down by A. & A.E.E., and subsequently recovered intact, D.Arm.D. decided that live trials with the operational bomb could no longer be delayed, and should not await the Orfordness ballistic results. Accordingly in April two live bombs were dropped by A. & A.E.E. at the Ashley Walk bombing range in the New Forest with highly satisfactory results.[1]

For this trial three tail pistols No. 58 were fitted in each bomb, these being modified standard No. 30 pistols.[2] The modification consisted principally in removing the air arming device, and substituting a star washer which held the striker from the detonator until impact. The striker and detonator were of the sensitive type—a sharp striker piercing a fulminate cap—now almost invariably used in modern bombs. The delay was 11 seconds, obtained from a standard No. 55 detonator, the filling was Torpex, height of release 18,000 feet and the airspeed 169 m.p.h. Each was fitted with a modified tail with off-set vanes to cause spinning. Both bombs were stable throughout their fall—approximately 36·5 seconds.

With the conclusion of this trial, the development of the bomb could be considered as complete, although more ballistic trials with the small 4,000 lb. model were still outstanding, and tests of the full size bomb against the Ministry of Home Security building target at Ashley Walk were thought advisable. It will be observed that the bombs so far released had not substantiated the 'earth shock' theory of Mr. Wallis: the craters though relatively shallow were not negligible: moreover the restriction in height to 18,000 feet imposed by the performance of the Lancaster prevented the full depth of penetration required by Mr. Wallis to support his theory. On the other hand the theory was by no means disproved, for none of the conditions of size and height of release required by the inventor had been fulfilled.

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[1] M. of S. File S.B. 50904/4.

[2] *See* Chapter 15.

The Ashley Walk trials were concluded towards the end of April. Six bombs were dropped from 18,000 feet but in this case short delays of 0·05 and 0·025 seconds were used. The average depth of crater with the first delay was 14 feet and with the second 19 feet. For a bomb of this size, these craters appeared unduly small and the results were discussed at M.A.P. by Group Captain Wynter Morgan D.D.Arm.D. (B), and the designer, Mr. Wallis, with the assistance of representatives from the Directorate of Machine Tools, and C.S.A.R., who had been responsible for the filling and detonating systems.[1]

The question at issue was whether detonations in the recent trials had been as far as could be judged, complete, and if so, how the efficiency of the bomb could be improved. Mr. Early, C.S.A.R.'s representative was satisfied that the system of initiating detonation and the exploder system were satisfactory and could suggest no modification which would improve them. Mr. Wallis reviewed the possibility of breaking up, and from his knowledge of the strength of the case, and the evidence of the earlier inert and live drops, concluded that the bombs had probably remained intact. The only remaining probable cause of the apparent failure was that depth of detonation was much more than would be expected from delays of 0·25 and 0·5 second. The meeting decided that deep penetration was the most likely solution, and that this was most probably due to delay in the operation of the inertia pistol.

Further trials were therefore considered necessary with instantaneous and extremely short delay detonators of 0·01 and 0·12 second. As there was just the possibility that partial premature detonation might have occurred, Mr. Early suggested that additional trials with modified fillings might be made. So far the Torpex used in Tallboy had been desensitized :[2] that is to say its sensitivity had been reduced, to lessen the risk of instantaneous detonation on impact. It was now proposed that four bombs should be filled with normal Torpex and that two of these should have slightly modified exploder systems with thinner end walls. It was known that single charges of Torpex of this composition, and in similar quantities would detonate completely, and there was no reason to suppose that it would behave otherwise in the Tallboy bomb. The thin ended exploder container was calculated to increase to some extent the efficiency of the exploder system.[3]

The first of these two series of trials—that involving instantaneous and short delay detonators—was completed by A. & A.E.E. late in April and gave no decisive results. The remaining trials were completed by the end of May, and gave no indication that Torpex without a desensitizing agent caused any improvement in crater size. It did not appear therefore that any improvement in the performance of Tallboy (M) could be expected, and as the ballistic trials of the 4,000 lb. model bomb had by that time been satisfactorily completed at Orfordness, so that accurate sighting data could be calculated, the Air Staff decided that the bomb should go immediately into operation.[4] Development and trial had occupied less than a year, and this included the design of hoisting and carrying systems in the Lancaster, special transporting trollies and numerous smaller items which go with the introduction of a bomb of unorthodox proportion.

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[1] M. of S. File S.B. 50904.
[2] By the addition of Beeswax.
[3] M. of S. File S.B. 50904/4.
[4] A.M. File C. 26698.

The new bomb was first used in operations in air attack on a railway tunnel near Saumur in June 1944; the attack was entirely successful, and although the target was not such as to test fully the special qualities—deep penetration and rupture of strong buildings by earth shock effect—the results impressed the Air Staff, who decided that they had 'every justification for anticipating increased operational use of the bomb, and for requesting an increase in production'.

So far, all production except the original small development order had been authorised solely by the Chief Executive, M.A.P. (Sir Wilfred Freeman), but in June the Air Staff increased the existing order for 325 Tallboys to 2,000 and the C.E. made immediate arrangements for 1,000 of these to be made in U.S.A. At that time, only one squadron was equipped with Lancasters suitably modified to carry the bomb, but concurrent with the demand for increased production, the Air Staff authorised the preparation of a second squadron, anticipating an expenditure by the two squadrons of 240 bombs each month.[1] Later in the year, three more squadrons were equipped with modified aircraft.

The immediate success of Tallboy (M) prompted the C.-in-C. Bomber Command to press for increased supplies and many more targets would have been dealt with had this been possible. At one period two weeks elapsed before a sufficient number could be accumulated to bomb the *Tirpitz*.

As lagging supplies became available, however, the bomb was used against an ever increasing variety of targets, particularly launching sites for pilotless aircraft and rocket projectiles in Northern France, and U-boat pens on the coasts of France, Holland, and Norway, and in the North German ports. An estimation value against these targets is given later in the Chapter. Having reached the stage where Tallboy (M) was in operational use, it is convenient now to leave the account of that bomb for the time being and turn to the re-introduction of the larger edition.

Development and production of Tallboy (L) (Grand Slam)

By July 1944 there had been opportunities to inspect some of the German-built structures in the Cherbourg peninsula. Examination of these, and the experience gained from dropping the 12,000 lb. Tallboy made it clear that that bomb was too small to destroy those kind of targets particularly with the 18,000 feet limit of operational height and arrangements were begun to produce the 22,000 lb. or 'Ten-Ton' bomb. Writing to C.A.S. on 14 July 1944 the Chief Executive stated that the C.-in-C. Bomber Command was pressing him to produce Tallboys (L) at the expense of the 'M' type. He reviewed the production prospects and estimated that it might even be possible to make 50 per month without interfering with the production of Tallboy (M), provided this could be fitted in with Admiralty work on which the industrial firms concerned were engaged.[2] C.A.S. took the matter up at a Chiefs of Staff's meeting the following day, pointing out that if the Tallboy (L) was to be of any use production ought to be at least 50 per month. Admiralty co-operation was soon obtained and on 24 July the Chief Executive informed C.A.S. that he had been able to arrange casting facilities for the required number of bombs—without interference with Tallboy (M)—commencing about January 1945.[3] This

[1] D.C.A.S. Folder R4/A. 30 June 1944.
[2] A.C.A.S.(T.R.) Folder B. 4/4. 15 July 1944.
[3] A.C.A.S.(T.R.) Folder B. 4/4. 24 July 1944 and 3 September 1944.

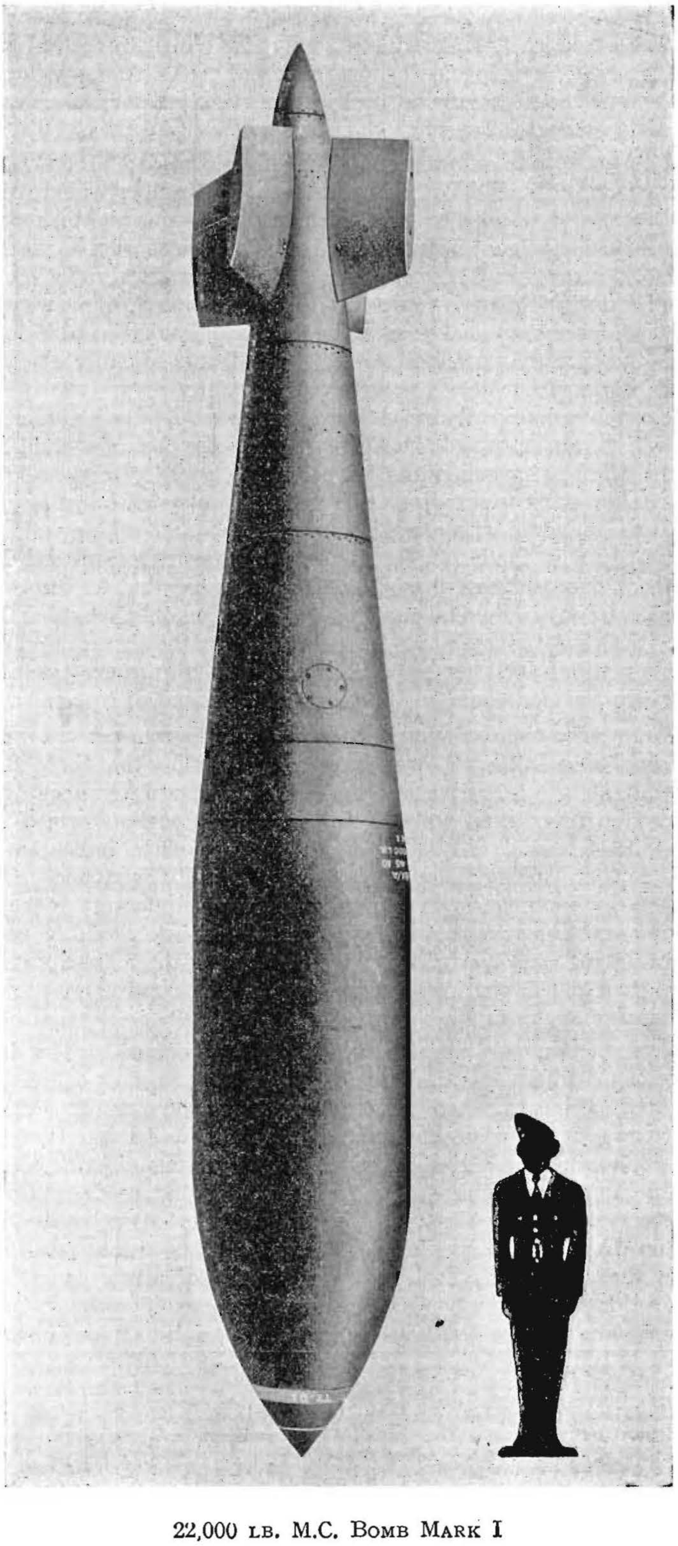
forecast was based on U.K. production only, for which the initial order was for 400 ; there was a further order for 200 from U.S.A. Along with this order for bombs went the necessary authority from Air Staff for the conversion of fifty Lancaster aircraft to carry the bombs.

Immediately afterwards however, the Air Staff reconsidered the whole matter, and with a forecast by the War Cabinet that 31 December would see the end of the European war, decided to cancel all bomb production and the modification to aircraft.[1] This decision, including as it did the cancellation of the American order, raised a strong protest from the British Air Commission in Washington, who considered it would have ' unfortunate repercussions '. This was a natural point of view, for a great deal of pressure had been brought to bear on the U.S. authorities to speed the production of Tallboy (M) and to undertake the manufacture of the larger bomb. It was feared that any future efforts to obtain increased output of urgently needed equipment would be prejudiced.[2] The British Air Commission urged the Air Staff to change their view and find some use for the bomb, suggesting that an order for say fifty might alleviate the position. If the decision was irrevocable B.A.C. requested full reasons for this latest change compared with previous urgency, ' so that we may endeavour to make our peace with the U.S.' C.A.S. again took the matter up with D.B. Ops. and Bomber Command, and it was tentatively agreed that 50 bombs (U.S.A.) and four aircraft only should be provided as soon as possible. Bomber Command agreement to this was given by the Deputy C.-in-C. in the absence of the C.-in-C., but on his return the latter requested Air Staff to increase the number of aircraft to ten and for them to be available by the end of November 1944.[3]

Thus the picture was changing once more, and the number of targets likely to be vulnerable to Tallboy (L) was increasing so rapidly that Sir Wilfred Freeman again took the initiative and arranged for manufacture in America to be resumed on its original scale. Writing to Sir Charles Portal (C.A.S.) on 17 October 1944 he said ' I have not waited for any official indication from the Air Ministry that Tallboy (Large) is now wanted, and I have instructed Fairey to approach the Americans asking them to resume manufacture at the old rate : I am taking action in this country.'[4] He went on to ask should he put original number of aircraft into conversion again. Replying the following day, C.A.S. confirmed the Chief Executive's action regarding the bombs and also asked for the full number of aircraft to be converted.[5]

Actual production was not this time to be long delayed. The design had existed prior to Tallboy (M), and nine bombs had been almost completed before the Air Staff cancellation had occurred in the previous month, and had been allowed to go forward for development and installation trials. There had been one likely hindrance, that being the inability of the manufacturers to produce the bombs in steel of higher tensile strength than that used for Tallboy (M). From experience gained with operational use of the latter bomb, Mr. Wallis was certain that the steel should be of the order of 50–55 tons per square inch, to obtain the strength necessary for penetration of heavy concrete targets. To help in this respect the bomb cases were increased in thickness from 1·5 to 1·75 inches, but even so Mr. Wallis suggested an improvement in the quality

[1] A.C.A.S.(T.R.) Folder B. 4/4. 25 September 1944.
[2] D.C.A.S. Folder R. 4/A. 29 September 1944.
[3] A.C.A.S.(T.R.) Folder B4/4.
[4] Sir Richard Fairey, head of the British Air Commission in Washington.
[5] A.C.A.S.(T.R.) Folder. 18 October 1944.



22,000 LB. M.C. BOMB MARK I

of the steel was necessary. The matter was discussed in detail at a meeting on 10 August 1944, at which Mr. Burton explained that in order to obtain the quality of steel quoted, oil hardening would be necessary, and only one furnace and bath existed for such large castings, *e.g.*, at the Sheffield Steel Corporation works. Either a small number of bombs might be thus produced—and segregated for special targets—the remainder being produced with a special air hardening process, or, all the bombs to be of the latter method giving a tensile strength in the region of 48–53 tons per square inch. It was therefore agreed that firms which could do oil hardening should do so, others would use the special air hardening.

Between August and October, development work on the original nine bombs had been going on, as well as the modification of one aircraft and the provision of hoisting gear, etc.

By the last week of October, the first large Tallboy (inert filled) had arrived at A. & A.E.E. for test. Handling and installation tests went on at A. & A.E.E. during November and by the end of that month the first air dropping trial had been completed. The release was from 20,000 feet; observation was difficult owing to cloud but there appeared to be a turning rate of 2 to 3 revolutions per second with slight oscillation. During the fall of the bomb the tail fairing became detached from the tail, but impact was vertical, nose down, and as far as could be seen the bomb remained intact. The aircraft had been fitted with a chronograph timing apparatus to test the special release slip, and a delay of 40·5 milli-seconds was recorded. Rectification of this and the tail fairing defect as well as various small modifications to hoisting and loading gear went on at A. & A.E.E. until the end of February 1945.[1] Meanwhile the line production of empty bombs was reviewed by M.A.P. in January to be as follows:—

December 1944	3
January 1945	9
February 1945	25
March 1945	50

and thereafter at the rate of 50 per month until the contracts (U.K. and U.S.A.) for 600 bombs were completed. Filling capacity was well able to cope with this rate of empties, and production of ancillary equipment was on a level with that of the bombs. All seemed set therefore, subject to a successful live drop trial—for the eventual use of 'Grand Slam' in operations.

On 13 March 1945 the first high explosive filled 'Grand Slam' was released at the Ashley Walk range from an A. & A.E.E. aircraft flying at approximately 16,000 feet, the filling being Torpex D.1. Rotation began immediately after release and ballistics were generally good. Detonation was muffled and no earth tremors were felt at 2,000 yards; a crater of 124 feet diameter and 30 feet deep was formed. Mr. Wallis and the various Air Ministry and M.A.P. experts present were completely satisfied with this trial.

The following day the first 'Grand Slam' bomb was used by Bomber Command in operations against the Bielefeld Viaducts in Germany. Thirteen Tallboys (M) and one 'Grand Slam' were dropped in this attack, but photographic interpretation failed to distinguish the results of individual bombs. As to actual result, six arches of one viaduct and seven of the other were totally

[1] M. of S. File S.B. 60643.

destroyed by three bombs—all near misses—some 20,000 tons of concrete and masonry being destroyed, and it seemed probable that 'Grand Slam' was responsible for a great deal of this damage.

In April 'Grand Slam' was formally approved and introduced as a service store, its name being later changed to the less picturesque one 'Bomb H.E. M.C. 22,000 lb.,' the British bomb being Mark I, the American Mark II.[1] Some details of the operational use of the bomb will follow, but it is appropriate to return now to the story of the smaller version—Tallboy (M).

Tallboy (M) (continued)

Following the successful operation against the Saumur Tunnel in June 1944, the production order was increased by 2,000 (1,000 U.S.A., 1,000 U.K.), and in connection with the former the American authorities gave all possible assistance in speeding up this further order. In response to appeals from the Chief of Air Staff and the Chief Executive (M.A.P.), the U.S. General Commanding Army Service of Supply (Gen. Somervill) arranged top priorities for this production.[2] The Chief of U.S. Bureau of Ordnance (Admiral Hussey) also made special arrangements for the filling of these bombs with Torpex because facilities in this country were inadequate to cope with the increased flow of empties.

From this country materials such as explodering components, desensitizing agents and gauges, were flown to the U.S.A. as well as full instructions for filling, and an explosive expert travelled with them to advise the U.S. Navy on the filling processes.[3] The result of their efforts was that between thirty and forty Tallboys were made ready for filling in July, with the promise of a further 100 in August and 150 in each subsequent month.

At home the new order for 1,000 had been allocated, and the Director of Machine Tools, consulted, saw no great difficulty in casting and machining these quantities, provided the appropriate priority was given, but commented that the filling rate (then 15 bombs per week) would have to be improved upon. Accordingly the Director General of Filling Factories was approached by D.Arm.D. and asked how best the filling rate could be improved.[4]

This filling problem was soon overcome with the issue on 29 June of the official Air Ministry requirements for Tallboy at the rate of 120 per month rising to 240 as soon as possible, this resulting in the provision of the necessary extra filling capacity.

By the end of August, forty-two bombs had been delivered to Bomber Command and the anticipated delivery rate of filled bombs was as follows :—[5]

	British.	*American.*	*Total.*
September	50	60	110
October	70	60	130
November	80	110	190
December	95	150	245
Total	295	380	675

In actual fact, by the end of the year, a total of 900 finished bomb cases had been produced.

[1] A.M. File C. 26699.
[2] A.C.A.S.(T.R.) Folder B. 4/4 10 July 1944.
[3] M. of S. File S.B. 60642.
[4] M. of S. File S.B. 50904/4
[5] M. of S. File S.B. 50904/5.

Little more need be said on the matter of production which went through as efficiently and smoothly as could be expected in view of the difficulties involved in the choice and availability of raw material, particularly steel alloys, and in the finding of casting, forging, and machining capacity in a country whose production facilities were already strained. The strongest criticism which can justly be made is, not that Bomber Command did not receive sufficient of these bombs, but that they did not receive them early enough.

Difficulties in production did occur, but were all met. Badly fitting tails were a source of legitimate annoyance to the users; in some instances bombs from America were found to be incapable of taking the standard exploder container, and arrangements had to be made for the manufacture of special containers for them. This involved not only extra work in the factory, but also in the maintenance units storing the bombs, as segregation of the defective cases was necessary. Such difficulties, particularly in that of a large bomb manufactured in two countries, were inevitable, and are remarked upon only for their comparative rarity.

Operational use of the Wallis bombs

Tallboy.—Between June 1944 and the end of the war in Europe 854 Tallboys were dropped by Bomber Command against such targets as shipping, V-weapon sites, submarine pens, bridges, dams, aqueducts and viaducts, and oil preparation and storage plants.[1] More detailed reports of the performance of the bomb against a variety of heavy reinforced concrete targets, including those at Hamburg, Heligoland, and Hitler's mountain residence at Berchtesgaden, are contained in the B.B.S.U. Weapon Effectiveness Panel Report issued in November 1947.[2]

From a study of the B.B.S.U. Report it will be noticed that the majority of targets attacked with this bomb were of protective concrete.[3] Although this was not the object behind the design of the bomb, its quality and strength of construction were such that it was able to inflict considerable damage in spite of the excessive shock encountered against such targets.

In support of the 'earth shock' theory behind the design of bomb however, the B.B.S.U. analysis shows that near misses up to 40 feet were more damaging to heavy reinforced concrete than direct hits. This damage in the main resulted from the effect of earth shock on the foundations, causing collapse of portions of the structure, and was most pronounced in that of brick and masonry bridges and viaducts. Against steel lattice girder bridges, near misses were equally effective, but the damage was attributed to blast effect (and crater debris) lifting the spans, rather than earth shock affecting the piers.

Following the formal introduction of Tallboy as Bomb H.E. 12,000 lb. D.P.[4] in September 1944, Bomber Command pointed out that the letters 'D.P.' had long been accepted in the fighting services as an abbreviation of 'Drill Purposes'. The Command mentioned that fuzings used with the bomb had varied from tail instantaneous to 30 minutes delay; thus deep penetration was sometimes

[1] Results of some of these attacks are given in Appendix 10, the observations in the last column being those of the Operations Research Section of Bomber Command.

[2] Report No. W.1 D.G.Arm. (W.F.S./3507).

[3] *See also* Appendix 10.

[4] Deep penetration.

precluded, and asked, 'in view of the regard with which this weapon is held' could such an 'unimaginative and inexact title' be changed to 'M.C.' This change in title was agreed to and remains the official name of the bomb, which places it in its correct category. Its charge/weight ratio (about 50 per cent.) places it in the medium capacity class; it is not, and was never claimed to be, an armour-piercing bomb.

'Grand Slam.'—Forty-one of these bombs were dropped by Bomber Command, all in 1945, during the closing months of the European War. As with the Tallboy the performance of this bomb has been analysed and reported on by the B.B.S.U. in the report previously referred to, and the conclusions agree in the main with those concerning the Tallboy. 'Grand Slam' caused the most effective damage from near misses, and its penetration from 16,000–18,000 feet was estimated to be: into sand and chalk, 60–75 feet; into clay, 90–100 feet, this being about one and a half times that of Tallboy.

The height quoted must be borne in mind as it was a limiting factor in the use of the bomb and was less than half of that visualised by Mr. Wallis when he formulated his theory on deep penetration and earth shock. Without belittling the merits of 'Grand Slam'—it was undoubtedly the best bomb used against heavy concrete structures—the B.B.S.U. Report suggests that for direct hit purposes a bomb of similar explosive capacity, capable of complete perforation without break-up or premature detonation, would have been about fifteen times as effective. It should be emphasised that this bomb, like Tallboy, was never designed for penetration of hard targets.

Conclusion

This account may be suitably concluded by an extract from a despatch on War Operations by Marshal of the Royal Air Force Sir Arthur Harris:—

> 'Small supplies of the 12,000 lb. bomb became available in the early summer of 1944, and the first attacks with these weapons met with instant success. A variety of targets was attacked including a number for which the bomb had never been designed—for instance, reinforced concrete structures. Although these bombs did not destroy these targets, they did considerable damage and forced the enemy to increase still further the heavy protection already provided against air attack. During the summer of 1944, the supply of these weapons was of a hand to mouth nature, and many targets would have been effectively dealt with had more bombs been available. In the autumn of 1944 three attacks were made with these bombs on the *Tirpitz*: the attack at Alten Fiord so damaged her bows that she crept into cover at Tromso at a speed of only 8 knots, and the third attack sank her.[1] As a result of the success of the 12,000 lb. bomb, production of the 22,000 lb. type was started. The first one was dropped against and wrecked the Bielefeld viaducts in the spring of 1945. Further bombs were used successfully against U-boat shelters in North-West Germany.'

[1] This is according to Bomber Command's visual observations. Post-war interrogation of German officers intimately concerned at that period, state, however, that this second raid on 29 October was successfully repulsed, and that such severe damage was done to the ship in the first attack on 15 September, that it was decided that it would be impossible to get the ship back to Germany for docking and major repairs. On this second raid accurate observation was rendered difficult by very efficient smoke screening.

CHAPTER 14

THE 'DAM BUSTER'

In the previous chapter mention is made of a paper prepared in 1940 by Mr. B. N. Wallis, a large proportion of which was devoted to the air attack of hydro-electric dams. In particular the author went into much detail concerning the destruction of the Möhne Dam in Germany enclosing the valley of the rivers Möhne and Heve and the probability of destroying it by earth shock wave using a 10 ton bomb.

On 16 May 1943 this dam was successfully attacked by a special squadron of Lancaster aircraft armed with a weapon designed by Mr. Wallis. It differed fundamentally from the deep penetration bomb of the designer's original paper, and the object of this chapter is to describe briefly the events leading to the design of this unique weapon.

The events of 1940 and 1941 which led to the temporary abandonment of the deep penetration bombs project are related in the previous chapter, but Mr. Wallis' theory regarding the attack of dams attracted the attention of the Director of Scientific Research (D.S.R.) in October 1940, and ultimately led to the design of this special mine.

Early experiments

In October 1940 Mr. Wallis visited D.S.R. (Dr. Pye) and, in exposition of his theory on the destruction of enemy dams, suggested that its practicability might be experimented on with models.[1] This was agreed to and D.S.R. arranged for a series of experiments to be carried out by the Road Research Laboratory[2] under the supervision of the Chief of the Branch, Dr. W. H. Glanville. Early tests using polar gelignite in the vicinity of concrete pipes moulded as arches, seemed to bear out Mr. Wallis' calculations regarding multiple arch dams, indicating that one ton of explosive would be likely to damage such a structure 4 feet thick if fired 62 feet away from it at a depth of 75 feet; whilst for an eight ton charge the corresponding figures would be 8 feet, 150 feet, and 125 feet respectively.

Later tests against plain and reinforced concrete models of multiple arch dams gave a whole series of figures for cracking and destruction by various charges against both types of concrete.[3] These showed sufficient promise to warrant further experiments against models of gravity type dams, a far more difficult problem, and an informal committee of the 'Air Attack on Dams Committee' was set up early in 1941 with D.S.R. as Chairman.

In November 1940 Mr. Wallis had been given access to a report prepared for the Air Ministry in 1939, on the construction of the Möhne Dam.[4] The report contained no very detailed description of the construction of the dam but

[1] M.A.P. File S.B. 12409.

[2] A branch of the Department of Scientific and Industrial Research (Ministry of Home Security).

[3] Details of the numerous experiments, almost all with models, are contained in a series of reports—Road Research Laboratory Reports A.R.C. Nos. 1–89. November 1940–September 1943.

[4] Prepared by Sir William Halcrow, a Member of the Institute of Civil Engineers.

research by Wallis into German technical papers, prepared at the time of building, and obtained from the library of the Institute of Civil Engineers, gave him the information he needed for the construction of a series of models. These, and others prepared by the Road Research Laboratory after similar research, played an important part in the experiments about to begin.

Before further reference to these experiments it may be as well to describe briefly the theory Wallis had expounded. The attack to be successful must be made at the water face of the dam: a charge, the size of which remained to be determined, was to be placed at some maximum distance below the water level and at some minimum distance from the base of the dam. A great proportion of the energy of the detonation wave would in those conditions be transmitted to the masonry and not reflected, whereas at the air face there would be practically 100 per cent. reflection. These transmitted waves should, if powerful enough, breach the dam.[1]

The experiments, practically all made with concrete models, were carried out by the staff of the Road Research Laboratory, and their story is an epic of the history of weapon design. Following the early experiments on model arch dams, tests had to be made with 1/50 scale models of a gravity dam of triangular section. These were 2 feet 9 inches high and 2 feet wide at the base, being made of poor quality concrete to represent rubble masonry, and were mounted in steel lined pits with water on one side up to 2 inches of the crest. The air face side was lightly covered with plaster of paris to make any cracking more easily visible. Charges of polar gelignite were fixed at the bottom of the pit at various distances from the water face, and the results recorded indicated that, on the full scale, 15,600 lb. of explosive at 150 feet from the base of the dam would produce severe damage.[2]

These results indicated in practical effect that it would be necessary to place a charge of eight tons in close proximity to the water face of a gravity dam, a most discouraging prospect. There were however, two points arising from the experiments to date (December 1940) :—

(*a*) The true scale or value of the 2 oz. model charge.

(*b*) The full scale effect of hydrostatic pressure available in a gravity dam.[3]

These matters were referred to the Road Research Laboratory by Sir Henry Tizard,[4] and a meeting of experts was held on 24 December 1940, which Mr. Wallis attended. The conclusions reached regarding gravity dams were that it was necessary to check the validity of small model tests by a large scale test, if a suitable dam could be found. It was decided to carry on laboratory tests on models which could be later utilized for large scale tests; one of the members present (Dr. Stradling) having mentioned a disused dam at Nant-y-Gro, in Wales.

The problem was of great interest to the Ministry of Home Security concerning the defence of our own water storage and supplies, and within a few days permission had been obtained from the Birmingham City Corporation to use the

[1] *See* 'A Note on the Method of Attacking against the Axis Power', B. N. Wallis, in A.M. File C.S. 8640.

[2] Road Research Laboratory Report No. A.R.C. 5.

[3] This, it was thought, would considerably assist in increasing the damage caused by initial disruption of the dam face by explosives, and it could not be reproduced for model experiments.

[4] Scientific Adviser to the Chief of the Air Staff.

dam for destruction tests, and the site had been inspected by several experts who were at the meeting. Drawings and details of constructions were provided and the Road Research Laboratory arranged for models to be made. Writing to Henry Tizard at the Ministry of Aircraft Production on 3 January 1941, Dr. Stradling outlined the latest proposals and asked for the backing of that Ministry.[1] This was given and with M.A.P. now officially interested in developments plans went ahead for the Nant-y-Gro dam experiments.

In February 1941 further tests were made against a 1/50th scale model of the Möhne dam; arrangements for these having been made some months previously. These tests confirmed the earlier deduction—as matters then stood—a large quantity of explosive being necessary if any serious damage was to be caused, but it is of interest here to digress on the construction of the model dams.[2]

The Möhne dam was formed of rubble masonry laid in cement mortar and in the model every known detail was faithfully represented. This entailed the making of hundreds of cement blocks measuring 0·4 by 0·3 by 0·2 inch and laying them in courses of fine cement mortar with a thin coat of rendering over the whole. The building of this accurate model, and indeed of all the models used in the long series of experiments, was the work of the Building Research Station at Watford, to designs resulting from the collaboration of the Road Research Laboratory and Mr. Wallis. Such then was the position when the newly formed Air Attack on Dams Committee (A.A.D.) held its first meeting under the chairmanship of D.S.R. on 10 March 1941 and discussed in great detail the experiments to date; in particular as to what further model experiments were necessary and to make arrangements for full scale experiments. Between that date and July 1942 a period of constant research and experiment on the part of experts in the Ministries of Aircraft Production and Home Security and Mr. Wallis, which included a full scale test against the Nant-y-Gro Dam, numerous tests were made to try and establish the theory of the gravity dam destruction and the practicability of designing a missile for that purpose.[3]

To attempt even a brief description of these experiments and the studies of the A.A.D. Committee up to July 1942, each a monument of careful and efficient observation, is beyond the scope of this account, and it is sufficient to note, that the full scale tests against the Nant-y-Gro Dam, in addition to confirming the indications of model tests, established the operational impracticability of destroying the Möhne Dam with the weapons available. Furthermore, the ultimate destruction of the Möhne Dam was wrought, not by the very large bomb originally envisaged by Mr. Wallis, but by a special weapon invented by him on realising that the limitations of bomb size, aircraft capacity and bomb aiming, precluded the practical operation of gravity dam destruction shown to be possible by experiments.

In July 1942 some time after the third meeting of the A.A.D. Committee, the general opinion of that body was that a dam of the size contemplated could not be expected to be completely destroyed by a charge of less than about 30,000 lb. weight of explosive placed upstream from the dam at not less than 50 feet from it. It was obvious that a charge of such weight was impossible to carry in a bomb or to transport in any known or contemplated aircraft, let

[1] M.A.P. File S.B. 12409.
[2] Road Research Laboratory Report No. A.R.C. 5, February 1941.
[3] M.A.P. File S.B. 12409 and Road Research Laboratory Reports M.A.P./A.R.C. 1—89.

alone to be dropped with such accuracy at night and in the face of enemy fighter attack and ground A.A. fire, and among the conclusions of the A.A.D. Committee at the time the following occurs :—

> 'There seems to be no doubt that attack on the Möhne Dam is impracticable with existing weapons unless a multiple charge technique can be developed.[1] This would undoubtedly be a long and difficult business and I think we can safely say that the gravity dam is a hopeless proposition.'

There is no doubt that with the knowledge available to the Committee this opinion was justified, but Mr. Wallis felt that this could not be the final word in a matter of such vast importance. Indeed it seems that he had already then given considerable thought to an alternative idea of placing a charge actually in contact with the water face of the dam. The idea was still predominant with Mr. Wallis, to quote D.S.R.

'. . . . I know the idea of the dam attack is very near to his heart . . . .' as indeed it was, in fact ten months later, in May 1943, the Möhne Dam was breached by a weapon designed by Mr. Wallis with the results well known to the world.[2]

The events briefly related up to now have been recorded to give some idea of the early experiments and the immense amount of careful patient research undertaken by all concerned in the Ministry of Aircraft Production (M.A.P.), the Ministry of Home Security (M.O.H.S.), and others too numerous to mention, in their efforts to obtain practical use of Mr. Wallis' theory on dam destruction. All the work involved was far from wasted, for with this new line of thought on the part of the inventor, the data already available could be usefully applied to experiments as to what reasonable amount of charge would be needed if placed in contact with the dam face.

So, with on the one hand the impracticability of the scheme, needing a huge weight of explosive—in orthodox bomb form—to be dropped with superlative accuracy, and, on the other hand, this latest turn of thought of the inventor, we must turn to the special mine designed by Mr. Wallis. It is a tribute to D.S.R.'s open-minded and generous treatment of Mr. Wallis that he should in the circumstances have agreed to the latter's request for further experiment in the face of the evidence against the project.

The 'Dam Buster'

This weapon, referred to at various stages in its development by a variety of names, was the invention of Mr. Wallis. The idea behind the weapon was a simple one and, in April 1942, Mr. Wallis produced a short paper describing his special mine. This paper examined the properties of the mine from the point of view of carriage in aircraft, explodering, air ballistics and underwater path, and showed that while the mine was unsuitable for penetration bombing it was ideal for underwater action. Other points put forward in favour of the mine were: ease of explodering compared with bombs of extreme size: uni-

[1] The multiple charge technique was employed to obtain detonation of bombs in the air by the use of specially sensitive fuzes. Bombs are dropped in rapid succession and the blast from one initiates the detonation of that following. Similar results might possibly be obtained under water; the scheme has been discussed for some time but no experiments had been made.

[2] M.A.P. File S.B. 12409.

formity in distribution of pressure and energy in the surrounding medium after detonation : insusceptibility to initial disturbance by the under-body turbulence of the carrying aircraft at the moment of release.

Wallis then considered the problem mathematically with reference to experiments carried out in Germany by Ramsauer, and then showed by experiments of his own that the cross-sectional density of the mine played an important part.[1] He had for some time foreseen the probability of the decision referred to earlier as to the impracticability of the size of charge, and it was this realisation that set him on the problem of how to get a much smaller charge right up against the dam face, and these early experiments of his are of particular interest.

While these and other experiments by Mr. Wallis were going on, the work of the Road Research Laboratory had been progressing towards finding the maximum charge necessary for worth-while damage from a contact explosion with the dam face. In the earlier months of 1942 this work had seemed likely to be called off, but following a report by D.S.R. to A.C.A.S.(T) in January 1942 the latter had agreed that it might proceed at low priority.[2] From the Air Staff point of view it was not at that time established that dams were in fact a profitable target,—' The project is not considered practicable at the present stage of the war. It might be considered later but then, as now however, it is likely that our bombing effort could be directed against targets of more immediate value.'

While this ' reprieve ' of his scheme was put into effect and the inventor had persuaded the A.A.D. Committee to authorise further experiments without disclosing the idea in the back of his mind, Wallis had completed his initial experiments and, in his own words ' . . . felt so anxious as to the possibilities of this extraordinary weapon on which I seem to have put my finger that, having great confidence in the intellectual power in my friend Professor P. S. Blackett I disclosed my new idea to him . . . '.[3]

To return to that document for a moment, Wallis had calculated not only the functional considerations of the mine but also the tactics of the aircraft which was to release it ; and finally a suggested method of construction which would enable the mine's density to be varied and obtain the best results.

Immediately following the receipt of Mr. Wallis' paper Professor Blackett[4] passed it on to Sir Henry Tizard who, within two days made arrangements for the use of a large experimental tank at the National Physical Laboratory, Teddington, and thereafter gave the new scheme his full support as did D.S.R. as soon as he was acquainted with it. A letter from D.S.R. to the Director, National Physical Laboratory (N.P.L.) on 22 May 1942 put the arrangements on a firm ' Service ' basis ; the N.P.L. co-operated immediately in arranging, at high priority, certain experiments in a large ship-testing tank at Teddington,[5] and henceforward communications between Wallis and the Laboratory were direct.

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[1] Weight per unit of cross-sectional area.
[2] M.A.P. File S.B. 12469.
[3] From Mr. Wallis' helpful criticism of the draft of this account. It was due to Professor Blackett's confidence in, and approval of, the new idea that Mr. Wallis prepared his original paper on the weapon in April 1942.
[4] The Scientific Adviser to the Board of Admiralty.
[5] M.A.P. File S.B. 37960.

For the experiments about to begin Wallis had made some two-inch model mines of varying density and an ingenious device for launching the mine in order to follow the calculated projectory.[1] Before exposing his theories to the experts of the N.P.L., Wallis conducted a number of trials at Vickers Armstrong's Works at Weybridge to convince himself that his theories were sound and, by the middle of June 1942, the launching apparatus was installed at Teddington, with, as target, a model dam of simple design built in concrete. For observation of the behaviour of the mine a searchlight and cinematograph camera were mounted in a water-tight transparent chamber in the tank so that the final under-water path of impact could be observed. This was, of course, the crux of the idea, for, in order that a charge capable of being carried in an aircraft should be effective, the early experiments of the Road Research Laboratory had shown that it must be in contact with, or at very short distance from, the face of the dam at the moment of detonation.

The initial experiments showed high promise, so much so, that following a demonstration on 21 June 1942, witnessed by several officials of M.A.P., the Controller of Research and Development (C.R.D.) wrote to D.S.R. :—

> 'I consider that the model experiments have established a clear case for an air test using full scale missiles. I therefore authorise the institution of such trials and agree to the allocation of a Wellington aircraft fitted for the carriage of 4,000 lb. H.C. bombs. I understand that the structural modifications to the aircraft are relatively small, in that they are concerned only with the modification of the bomb bay fairing.'

There followed, however, considerable discussions and an anxiety at the full scale size of the weapon Mr. Wallis had designed. This anxiety was understandable in consideration of the maximum permissible stowage within a Wellington aircraft. C.R.D. was responsible to the Air Staff for the adequate production of aircraft and weapons to maintain the maximum war effort, and any interference in the programme for standard or replacement bombers by modifications needed to carry missiles of an unorthodox shape and size had to be watched very carefully.[2]

The question of size was, however, decided by a visit of Members of the Directorate of Armament Development (D.Arm.D.) staff to Messrs. Vickers Works at Burhill where they found that Mr. Wallis' design, despite needing a special installation, involved modifications which were no more than those needed to convert the Wellington for the 4,000 lb. H.C. bomb. Good progress was made in the construction of ground testing rig which would assimilate the carrying of a number of missiles in a Wellington for full scale trials. Test-rig trials and installation tests on a Wellington aircraft went forward at great speed while Messrs. Vickers received a contract for such experimental work including the manufacture of inert missiles, and by 25 August 1942 such questions as mine density, a site for the forthcoming air trials, speed and altitude of release had been effectively settled. A strip of water some twelve miles long off Chesil Beach, West of Portland, was chosen for the trials, the target date for which was the last week in September 1942.

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[1] This work was done under the encouragement of Sir Henry Tizard with the kind permission of the Director of Vickers Armstrong Limited (from the inventor's review of this account).

[2] M.A.P. File S.B. 37960.

By the middle of September 1942 the first experimental empty mines had been made at Messrs. Vickers Armstrong's Works and eleven more were under construction. Arrangements for the Chesil Beach trials were completed by 1 October 1942, but the date of commencement was likely to be delayed until a satisfactory substitute filling of the calculated density could be decided. On that date D.S.R. reported to C.R.D. that the experiments on models and on the full scale dam in Wales were largely completed and from these it was shown that in all probability a much smaller amount of explosive in contact with the water face of the dam would breach it to a depth of 50 feet. The report went on to suggest that the required conditions might be met by the special weapon about to be tested and also gave a rough estimate of the size of the mine and its probable weight. D.S.R. also mentioned a suggestion by Sir Henry Tizard that Mr. Wallis should be requested to submit an opinion on the possibility of the mine being fitted to Stirling or Lancaster aircraft.

The reply of C.R.D. on 5 October is well worth quoting in some detail as it will serve as a summary to the main developments and leads to the position regarding the aircraft at that time.[1] Any aircraft survey was to be done on a Lancaster, C.R.D. having arranged for Mr. Wallis to have full dimensional particulars: full scale trials on the Wellington were to be concluded prior to any further work on aircraft. The probability of successful detonation of the explosive in its under-water position was to be examined at once, and C.R.D. was personally taking up with the Chiefs of Air Staff the broader operational aspects of the scheme.

By 24 November 1942 the experiments on successful detonation had been completed, but the Wellington trials had not taken place. Although a suitable inert filling had been approved, it would be necessary finally to do trials with an H.E. filling to see if the balance would be upset by the suggested tactical attack. Commenting upon the progress C.R.D. did not agree with D.S.R. that the Air Staff had come in as matters then stood as he had discussed the position fully with C.A.S. who was well aware of the aim behind the research and developments then going on.

By 3 December 1942 all was ready and the first trial bombs were dropped and photographed. Unfortunately, the peculiar construction of the mine proved too weak for the shock of impact, but even in their shattered condition the mines gave promise of future success. Further trials on 15 December with strengthened mines gave similar results, but several interesting features were revealed by the camera during the trials and gave further confirmation of Mr. Wallis' theories. As a final trial, dummy mines of solid wood were used in January 1943, and gave highly successful results.[2] The Chesil Beach trials had thus proved the mine to be no scientist's dream, but a practical weapon, and it only remained to decide to what use it could best be put.

The matter was officially referred to the Air Staff in a memorandum from C.R.D. to A.C.A.S.(T.R.) on 12 February, in which he analysed the technical possibilities of having the larger mine ready for an attack in the following April—Mr. Wallis' estimated opportune period—and which C.R.D. considered impossible. He was in favour of deferring the dam project until after similar mine experiments with Mosquito aircraft, considering in any case that it was a

[1] M.A.P. File S.B. 42186.
[2] M.A.P. File S.B. 37960.

clear issue of priority as between Vickers aircraft programme and the mine development. After full discussion between various members of the Air Staff it was agreed by C.A.S. on 19 February that the great potentialities of the mine justified pressing on with the development as soon as possible. Arrangements were made for three Lancasters to be modified for mine carriage, and sufficient modification sets for two squadrons were to be made, and manufacture of 100 mines.

On 26 February an important conference at high level was held at M.A.P., C.A.S. having given instructions that every endeavour was to be made to complete the aircraft and bombs for them to be used in the spring of 1943. The immediate requirement was for three Lancasters to be got ready for full scale trials. This was to be followed by conversion sets to complete 30 aircraft, and the requirement for mines had been raised to 150. All this work was to take precedence over other requirements at the firms concerned ; such was the importance the dam project had now assumed.[1]

The responsibility of the two firms was then detailed. Messrs. A. V. Roe were to make the mechanism for attachment and release in the bomb cells, while Messrs. Vickers were to be responsible for the mines. All the work would be done at Weybridge, where a detachment of craftsmen from Messrs. A. V. Roe would be sent at once. Mr. Wallis promised drawings for aircraft conversion in three weeks, for the mines within ten days, and a close liaison would be kept between himself and Mr. Chadwick[2] (A. V. Roe) on the many points of detail still outstanding and undecided.

The latest date the operation could take place in 1943 was 26 May, and it was decided that 1 May would be the target date for the mines to be ready, thus leaving only about eleven weeks, of which the last three were for final trials and crew training.[3] On the day following the conference there began a period of intense effort on the part of the designers and the aircraft firms concerned. The attitude of the latter was expressed in a letter from Mr. Chadwick to C.R.D. on 4 March, ' I should like to take the opportunity of saying that this project appears to be of such terrific possibilities that everything humanly possible will be done by us to make our part of the show successful.'

Investigations showed that the task was even greater than had been visualized at the preliminary conference ; the conversion of the Lancasters proved to be no easy matter of just fitting a ' conversion set ' into an aircraft. The changes were so great that they had to be built into the aircraft on the production line, and such aircraft had, therefore, to be segregated for the coming operation. C.R.D. was naturally pessimistic about producing either aircraft or mines in time, and said so in a report to the Air Staff on 6 March, but they accepted the segregation and agreed to a reduction of aircraft to twenty.

On 12 March C.R.D. decided to form a ' Co-ordination Committee ' of various Heads of Departments in M.A.P. and Air Staff, among its terms of reference being ' to co-ordinate the various development and construction programmes for

[1] M.A.P. File S.B. 42186.

[2] The late Sir Roy Chadwick, Chief Designer, Messrs. A. V. Roe.

[3] The month of April and May saw the greatest volume of water in the German catchments, a period when rivers and canals were generally independent of the reserves held by the dams.

which M.A.P. is responsible and to ensure that the complete article arrives at the place and by the date required by the Air Staff.' The Committee was to meet at least once a week, and the first meeting took place on the following day. Here estimates were given that the first aircraft would be ready by 1 April and the remaining twenty-two by the end of that month, while seventy-five filled mines would be available by that time. The Air Staff was asked to decide the squadron selected for the task and the aerodrome from which they would operate.

The importance of the project was reflected in a minute from the Minister of Aircraft Production to C.R.D. three days later when he wrote, ' there must be no falling down in this programme, which must be regarded as of vital importance.' C.R.D., in reply, assured the Minister that every one concerned was taking all possible steps to ensure success, but he pointed out that the whole project was a gamble based very largely on small scale experiments for which there was no sound technical data as a guarantee of success.

It was only by taking extreme measures that the hope of having aircraft, mines and crews ready for May was maintained, and on 17 March C.R.D. wrote to the Controller General of Production that it would be necessary for the firms to work 24 hours a day for seven days a week to achieve the programme.

While the aircraft firms worked night and day to produce the aircraft and mines, A.C.A.S. (Ops.) went ahead with the necessary arrangements for choice of squadron, bases for trials and final operations, training and all the necessary administrative details.[1] The object of this chapter is to describe briefly the development of the weapon and not to give an account of the operational plans ; it is sufficient therefore to record that No. 617 Squadron, Bomber Command, under the command of Wing Commander Guy Gibson, was formed to carry out the operation. Both training site and training base were selected, and arrangements for the preliminary trials placed under the Officer Commanding the Marine Aircraft Experimental Establishment.

At the end of March 1943 the position regarding development was that sixty-seven mines were made (forty were being inert filled, twenty-seven H.E. filled), and there was every hope that the trial and operational aircraft would be ready in time ; tentative delivery dates being then estimated that for the former 15 April and for the latter 8 May.[2] The period between 16 April and 12 May was one of intense activity by the development and trials staffs and the squadron crews. As well as the tactical training for the aircrews, trials were made with H.E. mines to test the impact, insensitivity and functional efficiency under operational conditions, all of which were successful.

On 12 May 1943 the Air Staff intimated in a report to the Chiefs of Staff Committee that the weapon was proved on trials, that the aircraft crews had been trained to an adequate standard of efficiency, and that for various operational reasons the time was ripe for the attack to be made. This was reported by the Vice C.O.S. Committee to the Chiefs of Staff, then attending ' Trident ' conference in Washington, who immediately sanctioned the operation for attack on German dams with the special mine.

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[1] M.A.P. File C.S. 8586/A.C.A.S.(Ops.).
[2] M.A.P. File S.B. 42186.

On 15 May a signal was sent by A.C.A.S (Ops.) to Bomber Command, 'Operation "Chastise"—immediate attack on targets "X," "Y" and "Z"[1] approved. Execute at first suitable opportunity.' The first suitable opportunity occurred the following night with the results now known to all the world: Mr Wallis' long years of research and labour were rewarded, his theories proved beyond all doubt.[2]

In this short narrative it has been possible to describe only a small fraction of the thought and effort which led to the perfection of this weapon which differed essentially from all others not only in design, but also in the fact that its use was limited to one objective.

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[1] Möhne, Eder and Sorpe dams respectively, A.M. File C.M.S. 33.

[2] It is not proposed to give a detailed account of the operation, but rather to include, as Appendix 16 to this volume, a translation of two reports by the President of Provincial Government of Arnsberg, Westphalia, on the Möhne Dam attack and the havoc it caused.

SUMMARY

It is proposed to end this Part with a brief summary of the effectiveness of the weapons reviewed and to make mention of a few points which may have become lost within the general framework.

Firstly, explosive fillings ; since they are mentioned in the chapter integral with the bomb, or series of bombs, are not dealt with separately. Their development up to 1939 was negligible and at that time, consisted basically of 80/20 Amatol and T.N.T. as used in the previous war. It is true that 'cyclonite' (afterwards known as R.D.X.), was in an advanced state of development, but unfortunately was not available in sufficient quantities in 1939. During the Second World War comprehensive research and experiments with bomb fillings were made resulting in the production or consideration, of many new and more powerful explosives such as Pentolite, Minol, Torpex and numerous others the majority of which contained a percentage of T.N.T.

It is not completely true to say that the General Purpose series of bombs was a failure although war experience soon showed that weights up to 500 lb., containing approximately 28 per cent. of a comparatively inefficient high explosive, were inefficient against many targets selected for attack. As a generalisation, General Purpose bombs had insufficient strength to obtain complete perforation of the target in a fit state to detonate, and insufficient explosive to do effective damage. The years spent in their development and trials had, however, established a number of fundamental facts, not the least of which was the most efficient shape, and the wealth of information so gathered was of immeasurable assistance in the design of the 'bigger and better' bombs which followed during the war.

An almost similar 'effectiveness construction' can be applied to the armour piercing and semi-armour piercing series which were produced in conjunction with the G.P. The success story for which both the 'piercing' and G.P. types of bomb must take part credit is of course in the eminently successful M.C. and H.C. Series.

The 'B' and 'W' bombs were to a large extent a waste of time and money and are examples of missiles which were technically sound, but operationally inappropriate. Effectiveness of Capital Ship bombs is still in the realms of the unknown and conditions of 'strike' appear to rule out its operational possibilities, it is perhaps significant that the development of this weapon was stopped whilst the *Tirpitz* was still afloat.

The Depth Charge, with its long record of success speaks for itself, but although the Anti-Submarine bomb, in the state in which it finished its war-time career, may be adequately described as abortive, some adaptation of such a weapon will no doubt supersede the D.C. in view of the great strides made in submarine development in recent years, and thus the effort expended may prove eventually to be other than wasted.

Of the development of incendiary bombs, little can be added to the exhaustive survey given in Chapter 6 except perhaps, to remind the reader that in the general opinion of the enemy there was little to choose between the fire-raising qualities of the 4 lb. and 30 lb. bombs. Both could be extinguished, removed or isolated by the prompt action of fire fighters, and their real value lay in their tactical employment with other weapons.

It is a matter of personal opinion whether it is a good or a bad thing that the effectiveness of chemical filled bombs cannot be accurately assessed ; sufficient to state that both chemical and bacteriological weapons were available should their employment have become necessary.

A special weapon developed for attacks against concrete protected targets and not reviewed in this narrative was the 4,500 lb. Rocket Assisted Bomb. It was designed solely to obtain a greater striking velocity for a given weight at reduced range. The small high explosive content of 500 lb. was not likely to prove effective against the type of target for which it was designed. The fuzing problem of igniting the rocket plus the variation in burning time of the rocket composition left little doubt that the weapon would be highly inaccurate. Untold effort was expended in designing, developing and manufacturing large numbers of this weapon, which was, however, used in limited quantities against U-boat pens towards the end of the war, but not with any marked success.

Among special weapons, the ' Dam Buster ' must take pride of place. In conception and design the work of Mr. B. N. Wallis, this missile was employed solely in the famous raid on the Möhne, Eder and Sorpe dams in May 1943. Of ingenious design and highly successful in operation, this bomb was produced in remarkably short time and the story of its development and production is an epic in the history of aerial bombs.

PART II

PISTOLS AND FUZES

INTRODUCTION

Part I of this volume has dealt with the main types of bomb used in the Royal Air Force and their development from the time when service aircraft changed their rôle from that of pure observation to the more aggressive use as a weapon of war. In the following chapters it is proposed to enlarge a little on the bomb story and give a brief outline of those integral components of bombs and numerous other missiles of an explosive or semi-explosive nature, the release of which has formed a major duty of flying branches of the services.[1]

The components referred to are those two main items the names of which comprise the title of this part of Volume I. Pistols and fuzes are used to initiate the main fillings of a variety of airborne missiles ; the main difference between them being that whereas a pistol is purely mechanical, a fuze does, within itself, contain some explosive in addition to the mechanical part.

The explosive or pyrotechnic composition which forms the main filling of bombs and flares must be ' stable '—that is to say safe to handle by people who fill, transport and load the missiles. It must be capable of withstanding very rough handling and severe blows, and it must be possible to release the missile from high altitude without functioning on contact with the ground. This requirement is included to allow the missiles to be released, in an emergency, over friendly territory, and for delay action purposes.

The pistols and fuzes are fitted with a safety device which ensures that the missile does not become ' live ' until it is some distance below the aircraft ; also, if accidentally dropped during loading, it will not become dangerous to handle. This safety device normally consists of a number of radial vanes attached to a spindle, which screws out of, or into, the pistol or fuze to make the component ' live.' These ' arming vanes ' rotate due to air pressure as the missile falls through the air.

The pistol is a simple device compared with the fuze, and it is, to a large extent, the type of operation for which the missile is required that decides which method is used. When an explosion on impact, or one occurring after a fixed period of time is required, a pistol is normally used ; whereas when variation of delay, with the possibility of pre-setting, or explosion before impact, is required, the fuze in the majority of cases answers the purpose. Both pistol and fuze can be produced to incorporate anti-handling devices to prevent missile immobilisation.

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[1] The early types of pistol are adequately covered in Appendix 12.

CHAPTER 15

NOSE AND TAIL PISTOLS

Development 1919–1939

In the inter-war period, bomb pistol development was almost negligible due generally to Air Staff policy and the lack of funds for the furtherance of armament. The progress which was made was mainly in modifications to improve the performance of old type pistols and to assist in their manufacture. The basic principles of both the nose and tail types, despite the occasional production of different pistols to fit new bombs, such as the G.P. series in 1925, remained unchanged for many years.

The ' Mark ' system was not generally employed and each altered or modified pistol was given a new number. Thus the No. 19 was a converted No. 8, its only difference being that it sometimes was manufactured with a cast iron body instead of brass. At the same time its use was extended to the 250 lb. G.P. Marks I, II and III bombs. It remained in use until stocks were finally exhausted in the early years of the second world war. A replacement pistol known as the No. 25 was designed in 1936 but, due to the cost of manufacture, was never put into production.[1] Similarly the No. 20 was in fact a converted No. 9 with the body sometimes made from cast iron but no other difference ; it also remained in use until none of the stocks of the old type R.L. bombs remained. Its suggested replacement the No. 26 was not produced for the same reasons as No. 25. The No. 16 suffered no alterations and finally disappeared from use in the early days of the Second World War.

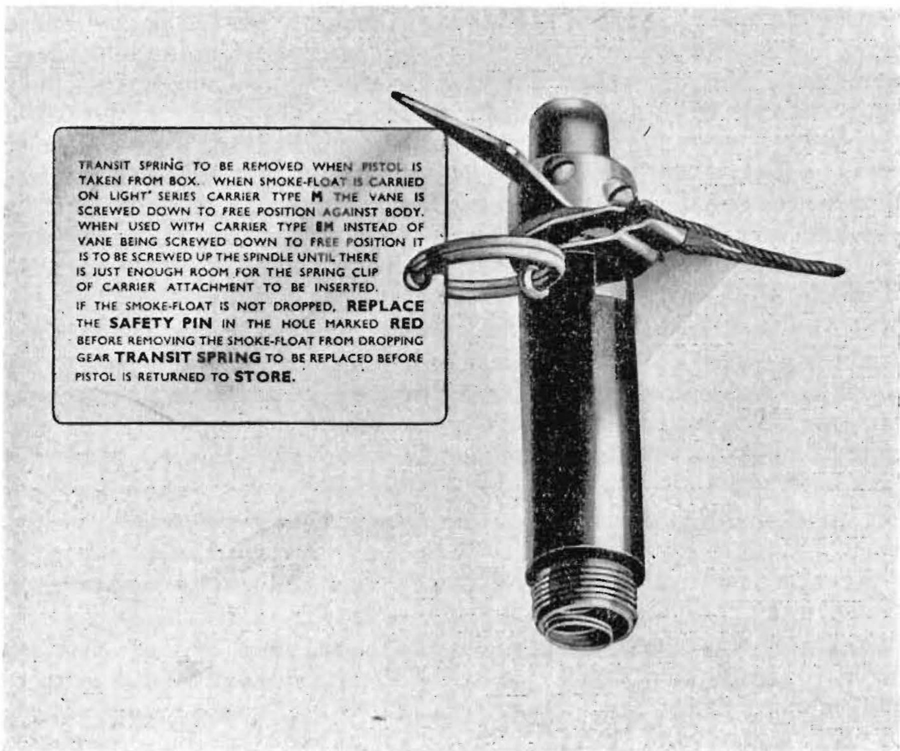
The design of the General Purpose Bomb Mark IV marked a new departure in bomb fuzing methods. Prior to its introduction, bombs had been fuzed by the ' central tube ' method : in this, a metal tube ran centrally through the bomb from nose to tail and into it were inserted separate intermediary exploders. The complete operations of fuzing was in consequence somewhat lengthy. In Mark IV, however, the bomb was manufactured complete with nose and tail exploders, and fuzing was reduced to the insertion of relevant detonators and screwing in the nose and tail pistols. This new method called for a new design of pistol and the No. 27 introduced in 1938 bore the distinction of being the first nose pistol to be manufactured to the new design and for a specific new type of bomb.[2] Its function and mode of operation followed the normal method but it was fitted with a locking device which secured it to the bomb.

Anti-personnel bombs, the 20 lb. ' F '[3] and the 40 lb. G.P. also required a new type of pistol, and No. 29 was specially designed and produced shortly after No. 27. The bombs instead of being carried singly on a carrier, were dropped in ' salvo ' from a Small Bomb Container (S.B.C.). Because their main use was to be against enemy troops the consequent low height of release made it necessary for them to be ready to function immediately after release. In order to achieve this, the No. 29 pistol dispensed with arming vanes and

[1] A.M. File S. 38711.
[2] A.M. File S. 398284.
[3] A.M. File S. 398284. ' F ' denoted fragmentation, the bomb replacing the 20 lb. ' Cooper '.

instead had a spring loaded dome ; this dome, held in position by a partition in the S.B.C., sprung off and the pistol became 'armed' (ready to operate), immediately the bombs were released. In order to meet the safety requirements the pistol was fitted with a phosphor-bronze shear wire which ensured that it would not function if accidentally dropped onto concrete during loading operations.

A very similar story pertains to the tail pistols ; No. 5 remained in use until old stocks of bombs were either used up or obsolete for operations.[1] The introduction of G.P. bombs in 1925 resulted in certain stocks of tail pistol 5B becoming modified to be known as No. 22. Another tail pistol, the No. 23, similar to No. 5B but having an aluminium body was produced in 1929 for use in a smoke bomb.[2] The bomb was a special one used as a navigational aid over water; but the pistol was of normal operation and, except for minor modifications, remained in use in its original form throughout the war.



No. 23 Pistol, Mark I

After a series of trials in 1937 a new tail pistol was introduced in January 1938 for use in 250 lb. and 500 lb. G.P. Mark IV bombs. This pistol, the No. 28, marked an innovation in tail pistol design in that it was the first to be used without arming vanes.[3] The reason was that, as previously mentioned, the

[1] Old type 520 lb. and 550 lb. R.A.F. bombs were still in existence as late as 1940, but were not used operationally during the war. It was arranged for their use as demolition charges for valuable installations in Bomber Command should the necessity arise. B.C. File S. 24388.

[2] A.M. File 896259/29.

[3] A.M. File 398375/35.

Mark IVs were produced complete with nose and tail exploders and as a consequence had no tail and did not conform to the best streamlined shape. A metal cone and tail were clipped to the main bomb to make the complete missile, thus hiding the tail pistol and preventing the usual air action on the arming vanes. Instead therefore, the pistol was fitted with an 'arming fork' which, when the tail was assembled, connected with a similar fork attached to a rod which passed through the bomb tail drum and had arming vanes at its rear end. Thus, whilst the bomb was falling, the arming vanes and rod rotated, unscrewing the arming fork on the pistol, and leaving the striker spindle free for normal inertia action on impact.

Development of sharp striker pistols

Prior to 1938 all bomb pistols, with the exception of No. 16 used in the 20 lb. 'Cooper,'[1] had blunt pointed strikers and were used with 'Anvil/Cap' detonators.[2] As is obvious, the lower the height of release, the smaller is the striking force on impact and the 'slower' the operation of both nose and tail pistols. The adoption in 1938 of low-level bombing with larger and heavier bombs, both over land and sea, indicated that their pistol/detonator combination was not sufficiently sensitive and, for this reason, allowed partial break-up of the bomb before its complete detonation. Also in the case of larger G.P. bombs, fuzed 'tail only' with a short delay detonator, a considerable loss in blast effect was observed due to the bombs being buried too deeply before exploding. The same effect was noted with both nose and tail 'instantaneous' when dropped on soft targets. Thus, while satisfactory from high altitudes, the use of pistols, 27, 28 and 29 from low heights caused concern.

In October 1938 successful trials were completed with anti-submarine bombs fuzed with No. 28 pistols and sensitive detonators, and in the following month the Ordnance Committee, in answer to a minute from the Director of Armament Development (D.Arm.D.) agreed that sharp striker pistols, which required less force, would improve the efficiency of high explosive bombs.[3]

January 1939 saw the approval of a new pistol for Anti-Submarine bombs. This pistol, the No. 30, was, except for a sharp pointed striker, identical with No. 28. With its introduction the 'Mark' system was utilised to differentiate between the modified No. 28 (No. 30 Mark I), and another of new manufacture, the 30 Mark II.[4]

Thus only two notable steps had been taken forward by the end of 1938, the arming fork method—to keep in step with the somewhat belated production of 'better ballistics'—and 'sharp pointed strikers' which was to prove its worth immeasurably in improving the reliability of high explosive bombs.

Development 1939–1945

Nose pistols

The failure rate of the No. 29 Pistol in 20 lb. and 40 lb. bombs when dropped on soft muddy ground was considered excessive; this was thought to be partly due to air pressure preventing the spring loaded cap from flying off and excessive

[1] A.M. File S. 398284.

[2] The initial flash was obtained by the force of the blunt pointed striker crushing the cap composition against another blunt point—the 'Anvil', within the detonator itself.

[3] O.C. Memos. 1527 and 1863.

[4] A.M. File 756870/38.

strength of the shear wire.[1] Modifications to the spring off cap were incorporated, and on 22 November 1939, representatives of the Ordnance Board,[2] Director of Operational Requirements (D.O.R.), various other Air Ministry departments and Bomber Command, met to discuss remedial action. After much discussion it was agreed to hold trials of the No. 29 using an aluminium shear wire instead of the phosphor bronze type then in use.[3]

The trials showed a marked increase in the reliability of the pistol thus modified, when dropped on soft ground from low heights, but it was thought that the modification would make it somewhat dangerous if accidentally dropped or if one bomb struck another on release.[4] D.O.R. considered a new pistol or fuze was the only answer to the trouble,[5] but despite these objections it was agreed to modify a proportion of the stocks by fitting the aluminium wire and only to use these pistols when the nature of the operations necessitated the risk.

While the improvement of the No. 29 Pistol was being considered, an urgent operational requirement arose for some form of parachute to be attached to 20 lb. and 40 lb. bombs to reduce the burying of the bomb, assist them to fall nose down and thereby give the pistol a better chance of operating and producing greater fragmentation. In November 1939 a new design of pistol, to be known as the No. 33, was approved and, after successful trials, was introduced into the Service in March 1940.[6] It used a thin copper washer instead of the normal shear wire and was of the spring operated dome type, similar to the No. 29. The dome, however, could not be forced off to arm the pistol until air resistance on the falling bomb had opened the parachute and the tug on the shroud lines had freed the spring clip from the dome.

No. 34 pistol

All modified No. 29 Pistols were renamed No. 34 and were generally used in bombing attacks below 500 feet; above that height the original No. 29 was used. In use the No. 34 proved to be extremely dangerous, for although more positive in action, its safety had been impaired and, as a result of a fatal accident in August 1941, when four 20 lb. and four 40 lb. bombs were accidentally released from a standing aircraft, Bomber Command recommended to Air Ministry that :—

(*a*) Use of the No. 34 Pistol should be discontinued except for special operations.

(*b*) 90 per cent. of the No. 34s then in stock should be converted back to No. 29s and manufacture of both types should be stopped.

(*c*) While stocks of No. 29s still existed they should be used only for high altitude bombing, and the No. 38 (then in limited supply), should be used for low level attacks.[7]

While these recommendations were under consideration, another fatal accident occurred. In November 1941 an aircraft of the Aeroplane and Armament Experimental Establishment (A. & A.E.E.) exploded in the air due

[1] A.M. File B. 37656/38.

[2] 'Committee' altered to 'Board' in January 1939.

[3] A shear wire is used in all nose pistols as a safety device to prevent the striker being driven by other than a heavy blow.

[4] Bombs fitted with this pistol were usually dropped in salvo from containers.

[5] *See* Pistol No. 38.

[6] A.M. File B. 37656/39.

[7] A.M. File B. 152264/40.

to premature explosion of a salvo of 20 lb. bombs fitted with No. 34 Pistols. On 7 December 1941, therefore, D.O.R. suspended the use of the pistol except for imperative operations against land targets below 1,000 feet or water targets from below 2,500 feet. Three days later the Assistant Chief of Air Staff (Technical) (A.C.A.S. (T)) confirmed this ruling.

No. 38 pistol

The No. 38 Pistol was the third to be used in small bombs for low level bombing and promised to overcome the troubles of the previous two. Numerous reports and recommendations had been made by Bomber Command to Air Ministry and all indicated the need for a new type pistol in 20 lb. and 40 lb. bombs.[1]

In February 1940 the Director of Armament Development (D.Arm.D.) informed the Ordnance Board that, pending the development of a blast-operated pistol, modification to improve the safety of No. 29 and No. 34 pistols by vane arming should be investigated. He pointed out that it was believed the Chief Superintendent of Design (C.S.D.) had under consideration a design similar to the No. 29 in which the dome had vanes and rotated on a threaded spindle.[2] In addition to arming vanes, the new design had a split metal collar fitted under the dome which would spring off the pistol after the dome had spun off.

In March 1940 C.S.D. sent a completed design to the Ordnance Board who recommended that fifty No. 34 pistols should be thus modified and tested. Very thorough trials were completed by July 1940 at A. & A.E.E. and the next month D.Arm.D. informed the Board that the trials had been successful and that it was desired to go ahead with production[3] using aluminium shear wires.

The Ordnance Board arranged for manufacture of the new pistol made of 'Mazak', a zinc alloy, and the only major difference to the No. 34 was the fitting of arming vanes (the split collar referred to earlier was not included).[4] Limited quantities were issued for operational use in September 1941 and soon afterwards adverse reports concerning their safety were being submitted. It was found that when used in 20 lb. 'F' bombs and carried in Small Bomb Containers (S.B.C.), the arming vanes rotated sufficiently during flight to make the pistol dangerous on release, also it was liable to operate if accidentally dropped from stationary aircraft.[5] The Ministry of Aircraft Production (M.A.P.) were informed and immediately commenced a further series of trials.[6]

In November 1941 D. Arm. D. reported to the Ordnance Board as follows :—

> 'In view of the unsatisfactory reports from the Service regarding the safety of the No. 38 Pistol, a series of investigations and trials have been carried out by A. & A.E.E. The principle defect reported was a tendency for the arming vanes to unscrew before release when carried in S.B.C.'s; although this feature had been tested in development trials.'

These recent trials had caused the following recommendations to be made to Air Staff :—

(*a*) Wedge fittings should be fitted to all No. 38 Pistols in service.

(*b*) Pistols with wedge fittings should only be carried in aircraft when the S.B.C.'s were not more than 6 feet from the ground.

[1] B.C. File 40793, Pts. I to IV.
[2] O.B. Proc. 4783.
[3] O.B. Procs. 5645 and 8174.
[4] O.B. Proc. 8915.
[5] B.C. File 40193/4.
[6] B.C. File 40783.

(*c*) Any wedge-fitted pistols that must be carried in S.B.C.'s more than 6 feet from the ground should have steel dome caps. (No. 38 made of zinc alloy.)

The Ordnance Board agreed with these proposals and on 25 January 1942 D. Arm. D. reported that all existing No. 38 Pistols had been fitted with wedges, but that the general design would remain, in view of the development of a 'blast-operated' pistol.[1] Meanwhile D.Arm.D. considered it advisable to have an interim sharp-striker design[2] as it would take some time to complete development trials of the 'blast-operated' type.

The adoption of sharp pointed pistols and sensitive detonators as standard fuzing for H.E. bombs

On 30 October 1941, at the request of Air Staff, an important meeting was held at M.A.P. to discuss the adoption of sensitive pistol and detonator fuzing as the standard method for H.E. bombs.[3] A full report of the proceedings is contained in the reference quoted and it is sufficient to say here that, after much technical discussion, it was agreed that a complete change over was to be made when supply permitted.

No. 42 pistol

This was the first nose pistol to be fitted with a sharp striker. It was introduced in September 1942 for use in the Mark IV G.P. and in M.C. bombs and, apart from improved safety and the sharp striker, was very similar to the original Mark IV G.P. pistol—the No. 27. Its official life was rather short, for in the next month its replacement—the No. 44 which was operated by blast, was introduced into the service.

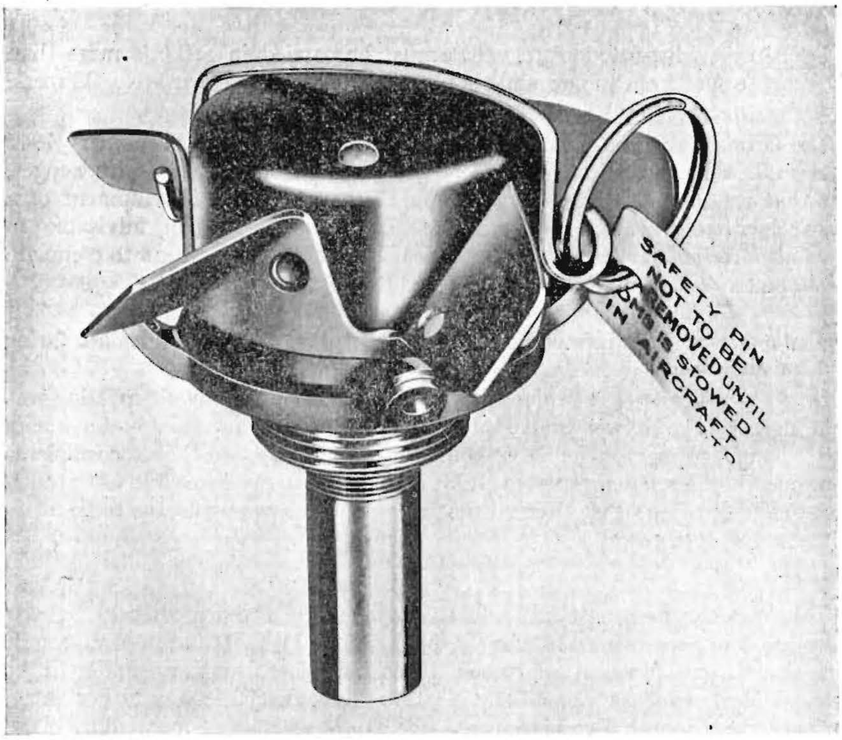
The 'Blast Operated' series

Although the use of sensitive fuzing had considerably improved the reliability of H.E. bombs, it became apparent in 1942 that there was room for even greater improvement particularly with fragmentation bombs. This need for improvement produced an important development in nose pistol functional design—the blast operated, or diaphragm type of pistol. Briefly the pistol was equipped with a 'needle' striker attached to a thin convex brass diaphragm which on impact, reversed its curvature and drove the needle into the detonator. The action was so rapid and sensitive that, when bombs were dropped in salvo, the blast wave of a nearby bomb was often sufficient to operate the pistol, and it was thought that, in some instances, increased pressure near the ground would also be adequate. There were difficulties but, they were mainly due to the design of bombs, and in general the system was highly satisfactory.

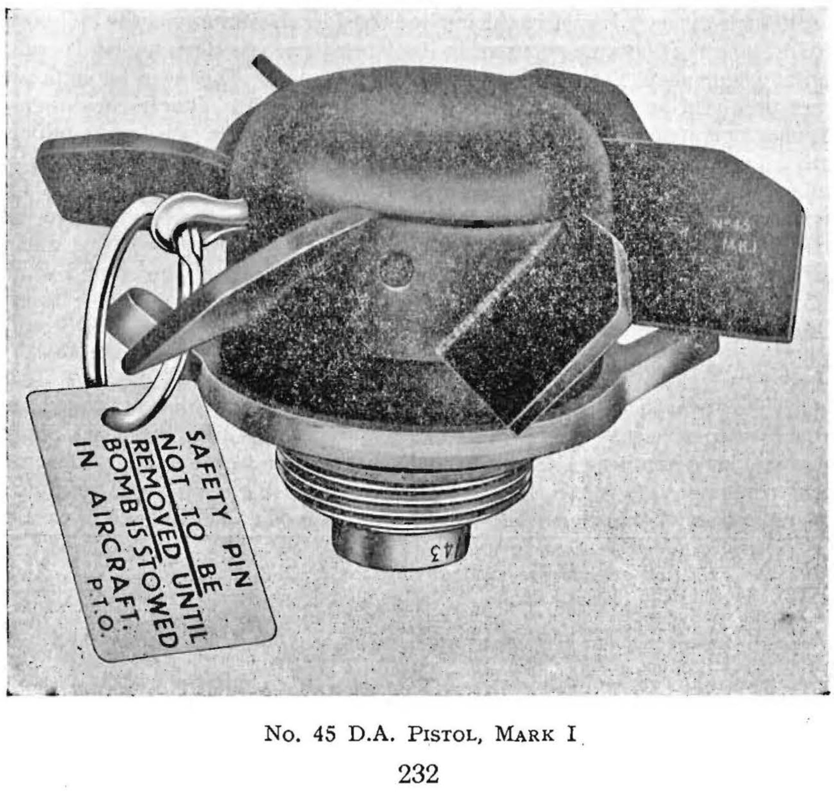
No. 44 and No. 45 pistols

Of these two pistols the No. 45 was actually the first to be approved and brought into service. It was designed in January 1942 by the Chief Superintendent of Armament Design (C.S.A.D.)[4] and after very successful development trials at A. & A.E.E. was approved in August of that year, to replace Nos. 29, 34 and 38 pistols.[5] The No. 44 was designed and developed in parallel

[1] O.B. Proc. 16131.
[2] *See* No. 42 Pistol. No. 38 was eventually replaced by No. 44 and No. 45.
[3] O.B. Proc. 14825.
[4] Late C.S.D.
[5] M.A.P. Files S.B. 34828 and S.B. 39236.



No. 44 D.A. Pistol, Mark III



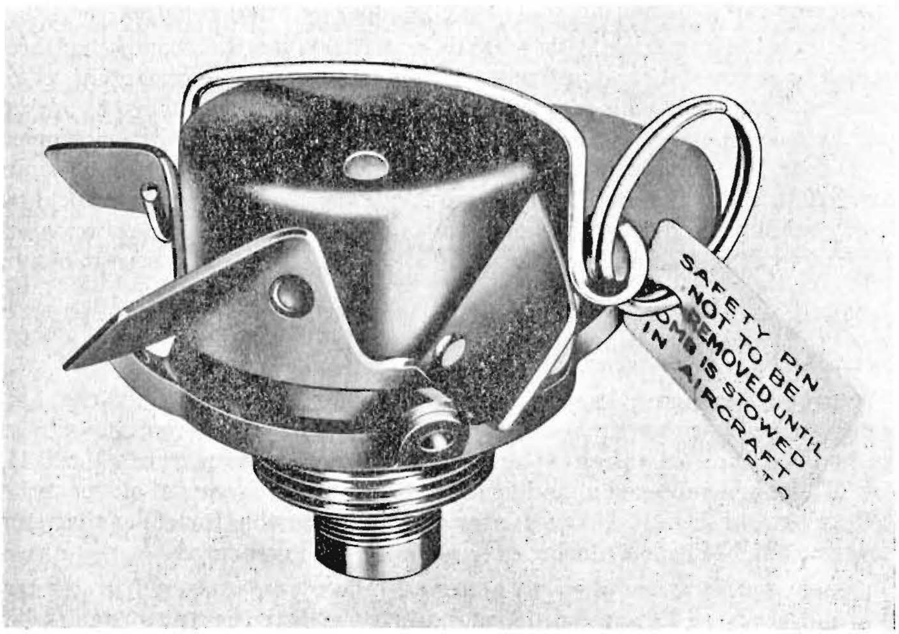
No. 45 D.A. Pistol, Mark I

with No. 45. It was a larger pistol, identical in principle, for use in G.P. and M.C. bombs up to 1,000 lb. weight, and replaced the No. 27 and No. 42 pistols. Like the No. 45 its trials were crowned with success and approval for use was given in October 1942.[1]

Two further types of the No. 44, Marks II and III, to fit M.C. bombs of up to 4,000 lb. weight differed very slightly from the original. They were fitted with a more sensitive diaphragm which gave more reliable air-bursting particularly in 'space-salvo' or 'short-stick' bombing. Of the pistols so far mentioned the Nos. 44 and 45 were the only ones to confirm, both in safety and reliability, their trials results, being highly successful in operations.

No. 52 pistol

The American bomb fuzing system was so different from our own that in order to fit their G.P. bombs with our pistol/detonator system, a shortened No. 44 Mark II pistol was used with a special small exploder tube known as a booster adaptor. The pistol was numbered 52 and after successful trials with 100 lb., 500 lb. and 1,000 lb. American G.P. bombs at A. & A.E.E. in November 1943, static detonation tests, and British aircraft bomb carriage suitability trials, production of No. 52, which later gave such operational satisfaction, commenced in March 1944.[2]



No. 52 D.A. Pistol, Mark II

No. 55 pistol

The introduction early in 1942 of the 4,000 lb. Marks II and III High Capacity bombs, brought with it pistol trouble. Three No. 27 pistols were initially fitted to the large, blunt and almost flat nose which, in order to give it a better

[1] M.A.P. File S.B. 39873.
[2] M.A.P. File S.B. 52331/1.

trajectory, carried an attachment known as a 'spoiler'. The pistols were positioned in a straight line on the nose with one in the centre, and the 'spoiler' although improving the bombs trajectory had a detrimental effect on the two outer pistols. Wind tunnel tests at the Royal Aircraft Establishment (R.A.E.) in August 1942 showed that up to speeds of 112 m.p.h. none of the three pistols had their arming vanes rotated.

Air trials using the No. 44 pistol in September produced a result almost as negative for only the centre pistol armed in flight. It was concluded that this was due to the disturbed air flow over the bomb's nose and R.A.E. commenced a series of experiments in an attempt to eliminate the fault. By December a form of extended arming vanes carrying hemispherical cups seemed the most likely to succeed, but despite successful wind tunnel tests completed by July 1943 with these anemometer type vanes, air trials were almost a complete failure. Apart from failure to arm in flight the pistol diaphragms were in fact operated by earth being forced, on impact, through the safety-pin holes in the dome cap indicating the probability of bombs detonating when jettisoned 'safe'.[1]

Many more methods were tried, including cutting small slots in the spoiler ring opposite the pistols, but it was not until December 1943 that marked improvement was obtained by turning the anemometer vanes through 45 degrees in the vertical plane and using a special safety pin which did not require holes in the dome cap and thus eliminated the previous 'earth detonating' action.

By March 1944 air trials with 4,000 lb. and 12,000 lb. H.C. bombs had been completely successful, and although some doubt with regard to safety on jettison still remained, this was outweighed by the pistols reliability to operate in all three nose positions. Trials with the 8,000 lb. H.C. bomb were incomplete by this date, but confirmation of the good results obtained with the other bombs were confidently anticipated, and the much modified No. 44 pistol, renamed the No. 55, was subsequently proved to be very reliable in operations and remained in its final form as the standard nose pistol for the High Capacity series of bombs.

Tail pistols

No. 30 Marks III, IV, V and VI

It will be remembered that the No. 30 was the first tail pistol to use the sharp pointed striker and to make use of the 'Mark' system to differentiate between the modified No. 28 (Mark I) and those of new manufacture (Mark II). Mark III, which embraced a modification to permit easy removal of the striker for cleaning and drying, followed later in 1939 when the drenching that anti-submarine bombs received during taxying made this necessary.[2]

Further trouble arose when an alarming failure rate appeared in January 1940, and trials at Lee-on-Solent established the fact that pistol faults had accounted for the majority of failures. From the details of the trials which were sent by the Director of Naval Ordnance (D.N.O.), to the Director of Armament Development (D.Arm.D.), the chief trouble seemed to be that either the arming fork did not completely unscrew the striker spindle nut or that the latter, even if unscrewed, fouled the striker and prevented its movement on impact.[3]

[1] M.A.P. File R/A 4219.
[2] A.M. File 756870/38 and O.B. Proc. 717.
[3] A.M. File 756870/38.

It was decided in April 1940, after further trials and experiments, that the main trouble was due to friction on the striker caused by transmission of torque from the revolving arming nut.[1] After very thorough trials, pistols with the plain portion of the striker spindle removed proved successful, and all No. 30 pistols were so modified, becoming Mark III, while those of new manufacture became Mark IV.[2] These modified pistols proved quite reliable in service, and although an identical pistol, but made in plastics—the Mark V—was produced, it, like the other plastic pistols, was a failure, and was withdrawn soon after its introduction.

In November 1943, Coastal Command reported two unaccountable accidents occurring during flight when an explosion occurred just below the aircraft. Their own investigations led them to suspect that the arming nut being jammed by the arming fork soon after release was the probable cause.[3] A conference held at the Air Ministry on 18 January 1944 between M.A.P., the Directorate of Servicing and Maintenance (D.S.M.) and Coastal Command, disclosed that three accidents in which the pistol was suspect had occurred. The experts present agreed that if the arming nut were jammed there would be sufficient striker protrusion to fire the detonator although it was difficult to see how the explosion could occur in operational use.

During the subsequent investigations of all tail units and pistols, another similar accident occurred, and in July 1944, D.Arm.D. suggested shortening the threaded end of the striker to ensure that, even if jammed, there was insufficient protrusion to fire the detonator. D.Arm.D.'s proposal was agreed to in the following month, and the Mark IV pistols, with the modification incorporated, became the last of the No. 30 series—the Mark VI.

A point of interest was the method used to ascertain the distance the bomb fell below the aircraft before the pistol became armed. A pistol was wired to complete a circuit when fully armed and ignite two flash bulbs attached to the bomb. Three cameras, two in the aircraft and one on the ground, produced photographs from which it was estimated that the pistol became fully armed after a fall of 7 feet. Apart from the few accidents reported and early troubles with the striker failing to operate, the No. 30 was a good standard tail pistol for many types of bomb, and the last and best of the series, the No. 30 Mark VI, remained in service in G.P., M.C., S.A.P. and A.S. bombs until the end of the war.

No. 49 Tail Pistol

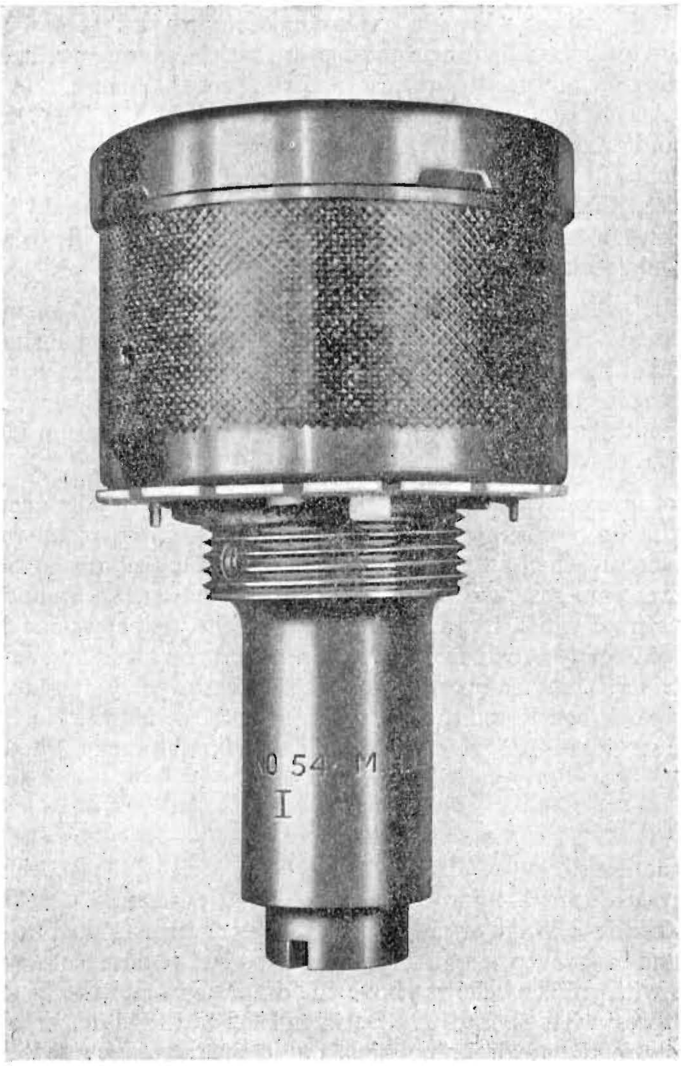
During the development of the Capital Ship (C.S.) Bomb early in 1942, a requirement arose for a hydrostatic pistol for a parachute C.S. bomb. The very low striking velocity of the bomb was insufficient to operate the normal tail pistol, and in order to meet the requirement a No. 44 nose pistol was modified for tail use with rubber bellows above the diaphragm and the head vented to allow water pressure to operate it. Between 1942 and 1943 the pistol was tested in various static and air dropping trials and in the latest recorded, A. & A.E.E. recommended that, as air trials were not satisfactory, further investigation

[1] O.B. Proc. 5716. After the arming fork had unscrewed the arming nut, the latter was supposed to revolve harmlessly around a non-threaded portion of the striker spindle.
[2] A.M. File 756870/38.
[3] M.A.P. File R/A 2841.

should commence into the effect of the parachute tail on pistol operation. This was, however, in August 1943, by which time the bomb itself had been abandoned and nothing more was heard of the No. 49.

No. 54 ' Multi-Ways ' Tail Pistol

An Air Staff requirement for a pistol which would function should the bomb land sideways was formed in October 1939, and by January of the next year such a pistol, designed by C.S.D., had been approved by the Ordnance Board.



NO. 54 TAIL PISTOL, MARK I

A number of experimental pistols were tried during 1940, but in August of that year, due to its complicated construction and excessive cost of production, the design was abandoned.

Little more was heard of a multi-ways pistol until July 1943, when D.Arm.D., perturbed by failures of G.P. and M.C. bombs armed with No. 28 and 30 pistols and released below 500 feet, wrote to the Ordnance Board and the Chief Engineer of Armament Design (C.E.A.D.) requesting an 'Allways' pistol design. C.E.A.D. rapidly produced a converted 30 Mark IV design, and by August 1943 a quantity of pistols had been converted.[1]

Unsatisfactory trials held at A. & A.E.E. between August and November led to its eventual abandonment in favour of an entirely new design, for in the words of the Ordnance Board, 'it is usually far better in the long run to start off with a new design rather than to try to make an already successful mechanism function equally well under different conditions.'

The new design, although operating on the same principle, that of a chamfered edged inertia ring, did not incorporate any of the existing parts and was completely successful in its trials during the last two months of 1943. Production at high priority was ordered in February 1944 after further success in high speed, low level trials from Typhoon aircraft, and the first production supplies for low level attack became available in May.

No. 58 Tail Pistol

The size and design of the tail unit of the Wallis bombs, 'Tallboy' and 'Grand Slam', for which this pistol was required, would not permit the normal air arming, and it was intended to use a clockwork pistol for the purpose. Probable delay in production, however, caused the reversion to a simple pistol based on No. 30 Mark IV. For the first time in a tail pistol a copper shear wire was used instead of the usual arming nut and nut spring, but it was found, in the trials of experimental models which were ready by 16 December 1943, that the strength of the shear wire prevented operation from 20,000 feet and instead a thin brass spider washer was fitted to the head of the striker.[2]

A production order was placed after successful trials with the new design in January 1944, and the pistol numbered 58 Mark I. There was a risk of failure if dropped from low level, but the size of the Wallis bombs for which it was intended, and its restriction of use to high altitudes only, precluded that possibility.

No. 60 Tail Pistol

The pistol, except for a modified arming nut to suit a special arming fork, was identical with the No. 54 'Allways' pistol. It was designed and developed for use with a limited number of 400 lb. incendiary bombs required for special operations in the Far East, but was never used.

No. 65 Tail Pistol

In 1944, it will be recalled, the No. 30 Mark VI was introduced to overcome the danger of prematures present in earlier types; these became more apparent when Bomber Command commenced intensive daylight bombing, and it appears that in February 1945 Bomber Command was not sure of Mark VI for the same reason. In the following month design details and a sample pistol, considered an improvement on the No. 30, were sent to D.Arm.D. for

[1] M.A.P. File S.B. 865.
[2] M.A.P. File S.B. 60331.

consideration. The new design, which provided for the arming nut to be attached to an arming screw so that on rotation both were completely withdrawn from the striker, was thought most promising, and, to test thoroughly the lightened striker, trials chiefly from 1,000 feet at the slowest possible speed over bog land and water, were completed successfully in March 1945. Approval and introduction into the Service of this new pistol (numbered 65) followed in June, and after the majority of the initial production order had been completed, modification of existing No. 30 pistols to No. 65, which became the standard direct action tail pistol for M.C. and G.P. bombs, commenced.

The use of plastic materials for bomb pistol bodies

With the declaration of war in September 1939, the expected increase in demand for metal, and its possible shortage, had to be envisaged, and in January 1940, when the possible shortages, particularly of brass, became probabilities, urgent consideration was given to the production of pistol and fuze bodies in plastic materials instead of the customary brass. A plastic design for the smoke-float pistol, the No. 23, had already been approved, but despite suggestions, and in fact decisions to produce, first the No. 27 pistol, and then the No. 41 fuze in ' Nestorite ', little positive progress seems to have been made till June of 1940.[1]

In that month it was recommended that the firm of Spearex Limited of London, with the assistance of the Chief Superintendent of Design (C.S.D.), should make twelve No. 28 tail pistol bodies for trial. This small order was rapidly executed and by July the twelve pistols, eight of ' Nestorite ' and four of ' Rockite ', had been so successfully tested in both ground and air trials at A. & A.E.E. that it was decided that in future the bodies of both Nos. 28 and 30 pistols should be of a plastic material with metal body threads.[2]

By October 1940, No. 28's and No. 30's were being manufactured but were not yet in operational use, and plastic models of the No. 27 were still in the experimental stage. Quantity issues of Nos. 28 and 30 were made to the service in the early days of 1941 but, as was the case with so many other types of bomb pistol, the plastic ones, despite their exhaustive development trials, did not give satisfaction in operational use.

Bomber Command in a report to the Ministry of Aircraft Production (M.A.P.) in March 1942, on the failure of No. 28 pistols both in operations and when jettisoned ' safe ' over this country, requested that more robust materials should be used since, in their opinion, plastics were too fragile to withstand the force of bomb impact.[3] Further tests and trials did not disprove this opinion and in July 1942, on the recommendation of D.Arm.D., the use of plastic pistols was restricted to 250 lb. G.P., 500 lb. G.P. and all M.C. bombs until such time as the supply position permitted their replacement in brass.

[1] O.B. Procs. 4120, 4566, 4661, 5856 and 6775.
[2] O.B. Procs. 7208, 7567, 7983 and 9657.
[3] M.A.P. File R/A 2941.

CHAPTER 16

LONG DELAY PISTOLS

The reason for 'delay action,' mentioned in many previous chapters in this Volume, has, by virtue of the need for initial penetration, been sufficiently obvious in itself to warrant no specific definition. This, however, does not necessarily apply to 'long delay,' and it must be stated, therefore, that in the majority of cases the main object was to deny the enemy the use and habitation of the area in which the bomb fell, until either detonation had occurred or the pistol responsible for the delay had been immobilised.

Many types of long delay pistols have been designed, but comparatively few have been used in service, due largely to exacting and, in some cases, impracticable requirements. For various reasons the theory that, if the pistols could not be disturbed or removed without instant detonation, any unexploded bomb would be suspected of being fuzed 'long delay' and would lead to evacuation of the area, dislocate the enemy's effort, and affect morale, was not always fulfilled.

Development 1919–1939

The original long delay pistol known as 'Fuze, Long Delay, McAlpine[1] Type' was used for special operations during the latter part of the 1914–1918 war, and is known to have provided delays of 6, 12 and 24 hours.[2] The word fuze in its title was somewhat misleading for it contained no explosive and was used in conjunction with the No. 5B tail pistol. On impact the pistol striker crushed an ampoule of acetone, which 'ate' through a celluloid washer, the thickness of which decided the delay. In 1922, therefore, its name was changed to 'Attachment/Long Delay No. 17,' and in late 1923, at the conclusion of suitability and safety trials, was approved for general use.[3]

This second designation did not last a great time, for numerous modifications in feasible delays, materials, and an eventual complete redesign, which included an arming device, changed its role for an 'attachment' to a complete pistol, and in 1925 it received its final name 'Pistol, Long Delay, No. 17'.[4] The pistol remained the only one of its type in service for a considerable period, for despite the general opinion that it was too costly, unreliable, and had a comparatively short life in the tropics, a suitable substitute could not be found.[5] Several alternative types were air tested but, apart from other difficulties, they all had the fault of protruding from the bomb tail and usually either broke away on impact, or could be cut off by the enemy.[6]

In April 1937 the Deputy Director of Operations (D.D.Ops.) suggested that it was of the greatest importance that up to 50 per cent. of the bomb pistols should be 'long delay' with varying delay periods. He emphasised the

[1] Designed by Mr. G. McAlpine, of Messrs. J. J. Griffin, Instrument Makers, London.
[2] O.C. Memo. 4535.
[3] O.C. Memos. 4691 and 5140.
[4] A.M. File 517434.
[5] O.C. Memos. B. 25161, B. 25871 and B. 26299.
[6] A.M. File S. 31998/33.

uselessness of the No. 17 in the latest G.P. bomb, the Mark IV, the unsatisfactory service which this pistol had given otherwise, and the urgent need for a replacement incorporating, if possible, an anti-handling device. As a result the Deputy Chief of Air Staff (D.C.A.S.) issued a directive which, because of the already complex operational requirement, deleted the anti-handling device and altered the quantity to 25 per cent.[1]

The promised pistol did not however materialise until early in the Second World War and, when in October 1938, it was forecast that a new pistol could not be produced before 1940, the already periodically amended supply percentage of No. 17 pistols, once again underwent an adjustment which entailed, as a consequence, firstly the reserving of earlier types of G.P. bombs, which were the only type which could utilise the No. 17, and finally the production of another centrally-tubed G.P. bomb—the Mark V, in order to keep pace with operational demands which could not be met by the later types of long delay pistols designed for Mark IV G.P. and similarly fuzed bombs.[2]

Early in 1939 Air Staff requirements, while still calling for a replacement with delays of 12 to 168 hours in steps of 12 hours, required in addition an anti-handling device and a means of exploding the bomb should any attempt to move it be made. Suggested designs were considered by the Ordnance Board at a conference on 30 March 1939 and it was decided that the most promising design, that by the Chief Superintendent of Design (C.S.D.), which was ultimately adopted, should have priority in development over both clockwork and osmosis[3] types suggested by R.A.E.

A number of designs were being investigated at the Royal Aircraft Establishment at Farnborough but none of these materialised, and at the outbreak of war in 1939, the No. 17 was still the only long delay pistol in use. Fortunately the tempo of the bombing offensive did not increase as it might well have done and the reserved stocks of old type G.P. bombs enabled the bomb load policy of 25 to 50 per cent. long delay fuzed, to be met until the replacement pistol for No. 17 was introduced.

Development during Second World War

No. 37 and 47 Pistols

The ultimate successor to the No. 17 was a product of the Design Department at Woolwich and was of the celluloid/acetone type. The first models of this pistol—the No. 37, could be adapted for delays of 6, 36, 72 or 144 hours and the possibility of failure was, to some extent, reduced by causing the ampoule of acetone to be broken by, and during the process of air arming.[4]

The first experimental models produced in April 1940, were successful in wind tunnel tests at R.A.E. in May, and, with the exception of the anti-handling device, gave fairly promising results on the air trials completed in July 1940, with inert and live G.P. Mark IV bombs. Requirements of any anti-handling device are to a large extent explained in the title, but No. 37 proved unreliable and dangerous for our own personnel to remove, should the aircraft return

[1] A.M. File S. 24335.
[2] A.M. File S. 24335 and B.C. File BC/S/22188/2.
[3] The ' osmotic ' principle was that of completing an electrical circuit by causing rubber to swell under the action of Toluene.
[4] O.B. Proc. 5380.

with the bombs.[1] Unfortunately urgent operational requirements late in 1940, caused the Air Staff to accept this none too satisfactory device, and pending its improvement, the No. 37 was produced in two types—Mark I without any anti-handling device, and Mark II for which many safety precautions were issued, the main one being that on no account was removal to be attempted from a bomb thus fuzed.[2]

No. 37 Mark III appeared in August 1941, when a much improved anti-handling device had been successfully tested. It was not long however, before this also revealed defects and an urgent need for modification. Bearing in mind the function of the anti-handling device, a serious danger to aircraft and crews was represented by the tendency of the complete pistol, or its head, to unscrew after release.[3] This defect was also apparent in the previous marks and, in January 1942, after a temporary remedy of an extra locking clip, approval was obtained for the reversal of the vane blades and arming spindle thread. Pistols thus modified were known as Mark IV.

In these early months of 1942, it became apparent that the enemy were not only aware of the function of the No. 37 pistols, but had discovered a method which presented little danger in their removal. To counter this, it was intended to replace the pistol with the No. 845 nose fuze, then under development, which was very sensitive to bomb movement, and, in March 1942, it was advised that the use of No. 37 Marks II, III and IV be restricted to urgent operations.[4] It transpired however that No. 37's were used throughout the whole of 1942 and long delay fuzing, when required, utilised No. 17 pistols in G.P. Mark V bombs.

Early in 1941, special low level attacks against canals and locks with high capacity (H.C.) bombs were envisaged, and, in order to allow the attacking aircraft to get clear before detonation, a delay fuzing of 30 minutes was required. For these operations nose delay fuzing was not practicable and in H.C. bombs there was no provision for tail initiation.[5] The problem was discussed between representatives of the Air Ministry, Ministry of Aircraft Production, Design Department, Woolwich, and Ordnance Board on 22 May 1941, and it was decided to fulfil the requirement by a modified design of No. 37 pistols fitted in the ' side pockets ' of the bombs.

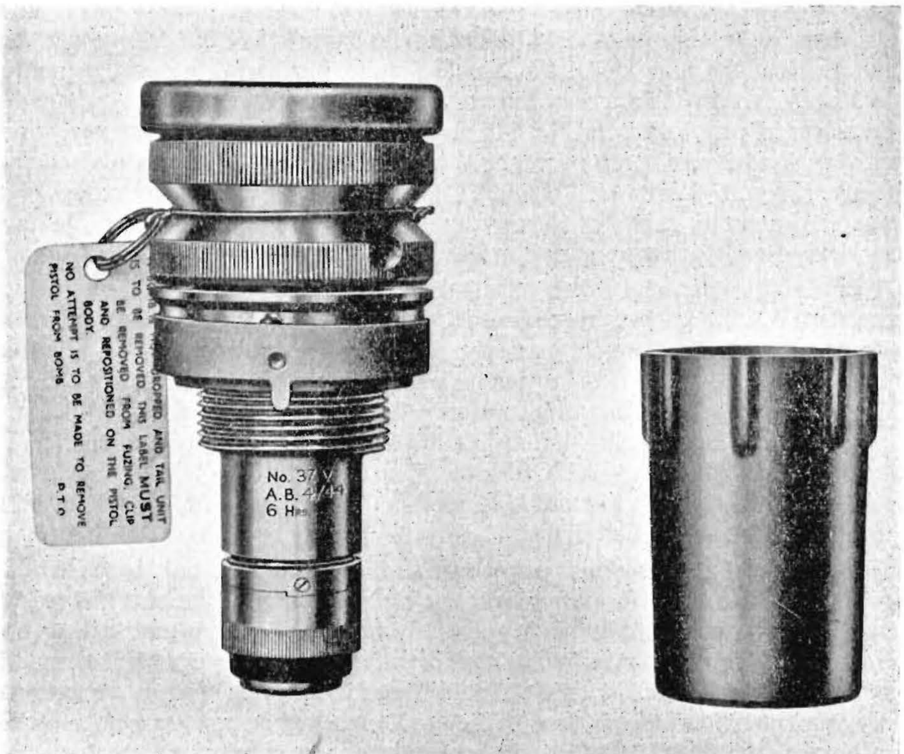
The action of this modified pistol was similar to No. 37, but, because of its positioning on the bomb, normal air arming was not possible and instead the arming spindle was fitted with a pulley around which was wound a length of cord with the free end attached to the aircraft. Two main troubles accrued in air trials at A. & A.E.E. in June ; firstly the arming spindle failed to rotate and crush the acetone ampoule due to the cord snapping on release, and secondly the bombs, the 4,000 lb. M.C. with parachute, cartwheeled and broke up on impact.

Trials in July with strengthened inert bombs and pistols fitted with a copper wire instead of cord, gave indication of eventual success, and after a special method of setting the spindle, prior to release and thereby minimising the possibility of failure, was adopted,[6] success was achieved late in July 1941 with a live 4,000 lb. bomb dropped into the sea from a low level.

[1] O.B. Procs. 6666, 7002, 7274, 7721 and 8207.
[2] A.M. File S. 24335.
[3] M.A.P. File S.B. 5790/3.
[4] M.A.P. File S.B. 5790/2.
[5] M.A.P. File S.B. 15186.
[6] M.A.P. File S.B. 30391.

A limited number of these 'Special Operations Pistols' were issued to Bomber Command by August of the same year and when it was decided soon afterwards, that they would be required for general service use, their title was changed to No. 47. Although the pistol seemed to satisfy operational requirements, they were apparently not used for the special operations and, in March 1942, further attempts to improve it commenced.[1]

The new design, proposed by the Directorate of Aeronautical Inspection (D.A.I.), differed chiefly from No. 47 in that the striker, instead of being anchored by a screw head in the celluloid washer, was retained in the safe position by steel balls. In addition a standard celluloid washer instead of a special one, and a solvent of 50/50 acetone/alcohol provided the time delay. Future production was to this design, but, as with the original No. 47, was not used in H.C. bombs for the 'Special Operations'; later however, in 1944, it was used with 'Tallboy' bombs.



No. 37 Tail Pistol Mark V with Bakelite Cover

1943 saw the No. 37 pistol once again in use but by this time the suspicion and mistrust, with which it was viewed by the Service, had considerably increased. The Director of Servicing and Maintenance (D.S.M.), commenting on several accidents attributed to the pistol, considered that a new method of handling should be introduced.

Despite an order, by Air Ministry in July 1943, that all pistols if accidentally dropped from standing aircraft or bomb trolleys were to be considered as

[1] M.A.P. File S.B. 61222.

'armed,' reports on the unreliability and accidents attributed to the pistol mounted. In reply to a lengthy report and urgent request for modification or replacement from Bomber Command, the Director of Operational Requirements (D.O.R.), stated that a replacement had had the highest priority request for some time but in the present stage of replacement development, to say 'how long' was impossible.

Fighter Command also requested investigations to produce a No. 37 pistol for special operations with G.P. Mark IV bombs, to give different delay times, but instead, these were obtained by combining the Nos. 47 and 37 pistols and varying the chemical strength of the acetone and the thickness of the celluloid washer. A modification, to give visual indication of the pistol's condition, was made by cutting three slots in the striker spindle and fitting a white blotting paper in the head of the pistol. Discoloured paper in these pistols, known as Mark V, detected a broken ampoule and the bombs thus affected could be segregated and destroyed.[1]

Interminable correspondence throughout 1943 and in the early months of 1944 brought to light the fact that our Bomb Disposal Service, who had found a means of removing the pistol with little danger, had discovered that misfires were occurring due to uneven dissolving of the celluloid washer. The generally unsatisfactory state of affairs was referred to in June 1944, by the Directorate of Armament Requirements (D.Arm.R.), who suggested that, operational necessity should be weighed against the accident casualty rate, and 'the discontinuation of use of No. 37 pistols should be seriously considered.'[2]

The percentage of accidents due to the No. 37, was however estimated at 1·3 per cent. and thus by July 1944, four variations of the original pistol were in use. Each variant was considered sufficiently important to warrant an advance in Mark (I to V) and to improve its safety and reliability. All these concerned the same principles but, despite innumerable conferences, investigations and modifications, the pistols were still unsatisfactory at the end of the war.

The abandonment of the anti-removal device in November 1944, coincided with fitting of a striker guide to overcome the difficulty of off-centre strikes by irregular solvent action on the celluloid washer. Ampoules made of brass were recommended but production difficulties prevented their use before hostilities ended.[3] At the last war-time meeting in April 1945 however, it was recorded that another pistol was in development in which the safety did not depend on the absence of acetone leakage, but instead was so designed that if this did occur the pistol could not fire.[4]

Instead of being used for the special operations with H.C. bombs for which it was designed, the No. 47 pistol was further developed as an alternative fuzing for 'Tallboy' bombs. Not long after the first attack with these weapons against canals and dykes in the summer of 1944, doubts as to the efficiency of the pistols for that type of bombing arose, and in October 1944 Bomber Command, reporting on such attacks, quoted one instance where four Tallboys, each fused with three No. 47 pistols, failed to detonate under-water after twenty-four hours.

[1] M.A.P. File S.B. 5790/4.
[2] M.A.P. File S.B. 5790/5.
[3] M.A.P. File S.B. 5790/7.
[4] M.A.P. File S.B. 5790/9.

Under-water tests however, seemed to establish fully the efficiency and reliability of the fuzing in these conditions and by early 1945, production of the pistols having increased, they were being used both in 'Tallboy' and 'Grandslam' bombs against U-boat bases and underground storage tanks. Short delays of half an hour or one hour were used but premature detonation was reported by Bomber Command quoting one attack in which of thirty-two bombs fuzed half an hour delay, seven had exploded on impact.[1]

Investigation into the cause of premature explosion was still proceeding when in June 1945 the reason of a similar fault in a later pistol, the No. 53, was shown to be occasioned by the striker sleeve. Similarity in that design indicated the fault of the No. 47 which after suitable modification became part of the standard fuzing of 'Tallboy' and 'Grandslam'.[2]

No. 53 Series

The No. 53 pistol was not of completely new design but a combination of its predecessors the No. 37 and No. 47 and was originally produced in the autumn of 1943 in response to Fighter Command's requirements for a short delay pistol for special operations.[3] The combination used the upper half of No. 37, and the lower of No. 47.[4] Some test models were completed in September 1943, and having shown satisfaction on trials, a small quantity with half hour delays, were sent to Bomber Command also for Special Operations—the requirements of Fighter Command having lapsed.

Although not fully satisfactory owing to the possibility of ampoule breakage in transit, the new pistols, chiefly because of the ball-retained striker, were thought to be a great improvement on earlier types. By March 1944, one hour delay pistols—the No. 53A, were also being produced and because of the short delays no anti-removal device was included in either pistols.

The failure reports and consequent under-water tests, previously mentioned with the No. 47 pistols, were applicable also to No. 53's which were used for similar operations. The No. 47's only were used for the tests, as, except for the No. 53 sealing off of the ampoule after arming, they were internally identical. About the same time, October 1944, all the usual complaints common to previous long delay pistols were prevalent concerning No. 53; in addition, doubt was expressed on the value of the blotting paper indicator, and the unsuitability of the glass ampoule.[5]

These defects caused considerable confusion among the pistol users, but, despite the great promise shown by brass ampoules, difficulties with production and the means of providing an effective sealing, resulted in none being fitted in No. 53 pistols. Earlier, in July of 1944, investigation trials in North Africa into missfires, showed that the main defect was off centre strikes on the detonator and a striker guide sleeve was produced to try to overcome this fault.[6]

Success seemed to have been achieved until April 1945 when a series of alarming accidents, from premature explosions of bombs fuzed with No. 53 pistols, occurred. Long and painstaking investigations into the numerous

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[1] M.A.P. File S.B. 61222/2.
[2] M.A.P. File S.B. 61222/3.
[3] M.A.P. File S.B. 15920/1.
[4] M.A.P. File S.B. 61222/1.
[5] M.A.P. File S.B. 15920/2.
[6] M.A.P. File S.B. 60759.

technical reasons which were advanced, led eventually to the discovery that the locking of the striker sleeve was faulty. It was found that vibration, unavoidable in aircraft, could cause the sleeve to rotate and that any rotation of more than a quarter of a turn was liable to operate the pistol.[1] Until modified to secure the striker sleeve, all No. 53 pistols were banned from use and this was the final modification to the No. 53 series. Although by no means fully satisfactory, the No. 53 long delay types did, after the final modification, give much more satisfaction and were comparatively less troublesome than other long delay pistols.

The numerical sequence of long delay pistol development has been discontinued at this stage for two main reasons, firstly those already recorded were, as the reader has no doubt realised, fundamentally the same pistol adapted from time to time for varying operations, greater safety, reliability and simplicity. Secondly they were all of the celluloid/acetone type which embraced all long delay pistols used in operations during the second world war.

Between 1925 and 1940 however, several other types, such as electrolytic, clockwork, or a combination of these, underwent experiment, but in June 1940, the Ordnance Board recommended that in view of the progress then made with celluloid/acetone pistols, work on other types should be abandoned.[2] Shortly after this recommendation however, the Royal Aircraft Establishment received instructions direct from the Prime Minister's office to design a new long delay pistol.[3] Such a pistol had in fact already been designed and eventually became known as No. 39.

No. 39 Long Delay Pistol

Although the requirement of this pistol was identical to the others already mentioned, its mode of operation differed ; it embodied the ' osmotic ' principle by means of which the completion of an electrical circuit was delayed until soft rubber pellets were swollen by the chemical toluene. The swelling of the rubber caused a time delay of about ten minutes before the pistol became operative, and after a further period, adjustable by means of a setting screw, completed an electrical circuit both to the anti-handling unit and the long delay initiation of the bomb.

Briefly, the sequence of operation was that, on release, the pistol arming vane rotated a cutter which split open the toluene capsule and started the swelling of the rubber ; on impact, inertia caused a spring loaded electric cell to set forward and make contact with an electric detonator ; about ten minutes after release the rubber pellets had swollen sufficiently to complete a circuit to a mercury switch which, if the pistol was disturbed, fired the detonator, and finally, if not disturbed and after a pre-set delay period, the long delay unit's circuit was completed and the bomb detonated.

Preliminary tests of the pistol showed such promise that all work on other types of rubber expansion pistols was abandoned and effort concentrated on No. 39. Air trials at A. & A.E.E. on the first of July 1940, did not however confirm the promise ; on hard targets, except for the anti-handling device, the pistol operation was very faulty, and on soft targets, although the pistols operated, pre-set delay times were at such variance as to be completely unreliable.

[1] M.A.P. File S.B. 15920/2.
[2] M.A.P. File S.B. 46905.
[3] M.A.P. File S.B. 7781/1.

Further trials with modified pistols on 16 July were also unsuccessful but did show that certain of the modifications had improved the operation, and that the pistol was now strong enough to withstand impacts greater than those which would cause break-up of the bomb. It was appreciated that timing errors would be greater for the shorter delays and that, due to not incorporating certain refinements to ensure accurate delays, to assist rapid and easy production, it was not possible to give an accurate statement of probable timing errors.

Further dropping trials with inert bombs were carried out in August 1940, and examination after the trials showed that of the eight bombs dropped, three would have exploded instantaneously, four on handling or after time delay, and one would have failed altogether. Although not entirely satisfactory, 1,000 experimental pistols were ordered and by October 1940, after small difficulties of production had been solved, twenty pistols were ready for service trials.[1]

Fifteen live drops, with pistols without the anti-handling device, were held at A. & A.E.E. in September and apart from irregularity in delay times—three set for two hours operated on impact, and three, for thirty hours, six hours and two hours, had not operated after eight days, the results were more promising. The bombs were dropped from varying heights between one and ten thousand feet on soft targets, and in all cases initiation of the pistol itself was satisfactory. Erratic delays, provided an efficient anti-handling device was fitted, were not considered of vital importance, and exceptionally long delays, thought to be caused by bombs coming to rest horizontally and preventing saturation of the rubber pellets, could be corrected with a small modification.

Modified pistols were tried in October and in the fifteen dropped, none functioned on impact, there was greater regularity in the operation of long delays, and only two failed to detonate. The following month six bombs were dropped to test the anti-handling device—all failed. After further modifications the six were again tested in December 1940 and this time two operated on impact, two failed to operate on removal, and two operated about two minutes after removal.

Once again R.A.E. carried out modifications but this time in three groups of six, each group differing in modification from the others. The trials carried out at Porton on 14 February 1941 with one of the groups, were more successful and it was decided to drop the remaining twelve pistols, modified as the first six and including locked setting screws and specially inspected igniters.[2] The trials took place at the end of February, all were released at 500 feet, four on to downland and the remainder on the concrete target.

Trial results were :—

(*a*) Seven pistols, including the four dropped on downland, did not arm,

(*b*) Three pistols fired at different intervals during or after disturbance.

(*c*) One fired prematurely and one failed due to a damaged igniter.

R.A.E. pointed out that, because of the danger of prematures, 1,000 feet had previously been agreed as the minimum height of release, and if the pistol was now desired to operate from 500 feet, the lack of usual deceleration caused by the flat trajectory from that height, indicated some form of 'All-ways' pistol requirement.[3]

[1] M.A.P. File S.B. 7781/1.

[2] During development of the pistol, the igniter, which fired the bomb detonator on operation of the pistol, had given continuous trouble.

[3] M.A.P. File S.B. 7781/2.

A conference, to decide further progress of the pistol, and held at the Ministry of Aircraft Production on 13 March 1941, decided that :—

(a) Further low altitude trials unnecessary since such operational use improbable.

(b) Provided anti-handling device was successful ; previous trials for long delay reliability being considered fairly satisfactory, pistol ready for introduction into the Service.

(c) Necessary to test private factory production pistols. Trials of twenty pistols to be arranged for testing separately the anti-disturbance, and long delay units, the former from heights sufficient to prevent bomb ricochet, and the latter at 4,000 and 10,000 feet.

(d) Special precautions to be taken to ensure that correctly produced igniters were available for the trials.

Twenty pistols from factory production were tested at A. & A.E.E. between 9 and 12 August 1941, faulty production of igniters and supply difficulties with main electric cells and mercury cells having held up production. Of eight tested for long delay, all functioned but again with erratic time delays ; of the twelve tried for anti-disturbance, one broke up and another operated on impact ; six, of which two operated correctly, were deliberately disturbed after impact, and the remaining four operated on removal from the bomb.

The erratic time delays were considered acceptable as a nuisance value, as was the anti-disturbance unit since it might operate either on disturbance or during removal. The pistol was recommended for introduction into the Service in September 1941 with rough usage and climatic trials still be to completed. Approval for introduction was given in the same month but its use was restricted, until No. 845 (anti-disturbance) nose fuze was ready for issue. To assist supervision the fuzes were to be issued to one bomber group only.

Further trials of this pistol, now known as No. 39 Mark I, were almost continuous during the next two years but efficient results were seldom obtained, and in late 1943, in view of the man hours required for the pistol's preparation under adequate supervision, and the limited number of special pistols of this nature which could be accepted, the Air Staff stated that No. 39 was no longer a requirement.[1]

[1] O.B. Proc. No. 25564.

CHAPTER 17

BOMB FUZES

The last two chapters of this part of the volume are devoted to the design and development of fuzes, Chapter 17 to bomb fuzes, and Chapter 18 to pyrotechnic fuzes ; it is perhaps worthwhile before doing so, to outline very briefly the main difference between pistols and fuzes and to give a short explanation for the use of the latter.

Firstly the pistol, which is normally used when a fixed purpose can be employed in the detonation of a bomb, is, because it contains no explosive, of a simpler design, safer in storage, and easier to transport. The fuze, however, has directly opposite properties to those of the pistol and is invariably used when, the operational requirements are too complex to be met by a pistol/detonator combination, the missile is required to burst in the air ; the exploder system of a bomb does not permit the pistol/detonator system of initiation, and when a variation of delay, which can be pre-set, is required.

The first initiating device for aerial bombs was in fact a fuze ; known as Fuze D.A. No. 1, the number being given to differentiate it from numerous Naval and Army shell fuzes then in use, it was a direct action nose fuze used in 65 lb., 100 lb., and 112 lb. H.E. bombs during 1915 and 1916.[1] The fuze was replaced by a pistol in 1916, and from then until the end of the First World War, requirements for bomb fuzes having ceased, no further development occurred.

The earliest traceable reference to fuze development after 1918 is found in a list of ' Fuzes for Use with Aerial Bombs ' in progress in 1923. The list comprised two nose and two tail fuzes, three of which were, years afterwards, produced for Service use, and those initial four fuzes were the only R.A.F. items on the Ordnance Committee's development list.[2]

No. 32 Anti-Submarine Bomb Fuze

The Air Staff programme for revised bomb design in 1922 included the anti-submarine bomb, for which a fuze was the stated requirement. Development of the fuze, the No. 32, commenced in 1923,[3] but exacting and impracticable operational requirements led eventually to its abandonment, during the Second World War, in favour of a simple tail pistol.

In its original design the fuze, fitted in the bomb nose, protruded for the greater part of its length ; it was air armed and a reduction gearing ensured a fall of 200 feet before becoming ' live '. Provision was made for instantaneous action should the bomb strike a surfaced submarine or for delay action should the vessel be submerged. In order to meet the complex Air Staff and Naval requirements, watertightness, simplicity, and variable depth settings for delay were attempted.[4]

The very nature of its requirements, however, made simplicity impossible and this, the most complicated fuze ever designed, possessed, due to its protrusion, a completely unpredicatable trajectory and was never watertight. After twelve years of slow but continuous research and development, little real

[1] Ordnance Board Annual Report 1915, p. 159.
[2] O.B. Annual Report 1923, p. 294.
[3] A.M. File S. 22761/1.
[4] O.C. Memo. B. 6729.

progress had been made and in August 1935, trials with model A.S. bombs at Farnborough, proved that even if the fuze could be made fairly reliable a bomb so fitted would, due to its hopelessly irregular underwater path, be almost completely useless.

At an Air Ministry conference on 16 August 1935, representatives of the Admiralty accepted a proposal to relax the requirement to one of fixed delay only, which could be met with a simple tail pistol. Unfortunately this was not acceptable to Air Staff, and so by 1936 a Mark II version of this most unsuccessful fuze had been designed. Experiments proved that a satisfactory underwater path could be obtained either by redesign of the bomb to accommodate entirely the fuze body, or enclosing the fuze with a ' bomb ballistic cap '. The increasing urgency to produce at least some A/S bombs and fuzes, resulted in the adoption of the more rapid ' ballistic cap ' method, and trials of the redesigned Mark II continued throughout 1937.[1]

A complete and detailed account of these trials is given in the reference quoted but results are sufficiently indicated by the fact that modification continued until February 1938 when, although still far from satisfactory, quantity production had been commenced. In September, production was stopped pending investigations into the latest type of waterproofing and check of the inertia pellet system. A complicated modification was recommended but fortunately the alternative to this modification, the fitting of a more sensitive detonator, was adopted in December 1938 and enabled production to be resumed in January 1939.[2]

The first confirmatory trials of production fuzes, commenced in February and lasting till August 1939, merely added to the already long list of troubles producing yet further modifications. In September 1939 a technical leaflet gave instructions for a long and involved process for preparing and fitting the fuze to the bombs, but after sixteen years of development and trial, this most unreliable fuze was still the only fuzing arrangement for anti-submarine bombs.

Progress after the outbreak of war was practically negligible for in November 1939 all production ceased.[3] Reports from user operational commands frequently mentioned failure of the fuze, and although in 1941 a Mark IV type was introduced, it did little towards functional improvement, in fact, until 1942 when an improved A.S. bomb with a hydrostatic fuze became available, the anti-submarine bomb was increasingly replaced by the depth charge and thus the No. 32 Fuze was but little used.

Nos. 30 and 31 fuzes for S.A.P. bombs

When the development of the S.A.P. bombs commenced in 1924 the fuzing requirements included a tail fuze as initiator. At that time there was a fuze under development for A.P. bombs and at an Air Ministry meeting in March 1925,[4] it was agreed that a similar fuze, suitably modified, might meet Air Staff requirements. Of these the main considerations were :—

(*a*) It must operate after passing through the first deck of 1 inch thickness, but must be sufficiently insensitive not to operate on light superstructures.

(*b*) It must operate after it has travelled an average of 4 feet after impact.

[1] A.M. File S. 22761/3 and O.C. Memo. B. 36006.
[2] A.M. File S. 22761/4.
[3] A.M. File S. 22761/5.
[4] O.C. Memo. B. 8132.

In November 1925 a prototype design had been completed and models were to undergo trials. It was a base percussion fuze containing two strikered inertia pellets, which, after arming, were held off their detonators by a creep spring and shear wire respectively, the detonators being shielded by a shutter until arming was complete.[1] The spring-supported pellet was intended to operate if the bomb struck water or other low resistant target and to detonate after a delay. The other pellet was intended to be 'blind' on a ship's superstructure, but operate after striking 1 inch plate with a delay as short as possible.

Development

It was eight years before the first type of fuze (No. 30) was introduced for Service use. As it has long since been declared obsolete, only an outline of the main events will be given here. Early design improvements and static trials went on until autumn 1928, when it was thought that the fuze was suitable for air trials. These were, however, held up by the fire at Woolwich Arsenal, until April 1929, when it was discovered that the fuze was dangerous in that it would arm and fire from as low as 20 feet.[2] This necessitated modifications, which were completed by March 1930, when, although the fuze was satisfactory as to safety height, it would not operate from 16,000 feet on water. More redesign and trials followed, and it was June 1932 before this fault was rectified.

In February 1932 fairly successful trials were completed against H.M.S. *Marlborough*, a trial ship of that period, and as an outcome the Air Staff requirement for a short delay was abandoned, it being concluded that a bomb was likely to be detonated by 'any robust obstruction' above the deck.[3] In January 1933 the fuze was introduced into the Service: the No. 30 for 250 lb. S.A.P. bombs, the No. 31 for the 500 lb. size, the only difference being in the thickness of the shear wire.[4] Later in the year, at the annual Bombs and Torpedo Conference, it was decided that, in addition to the removal of the 'short delay' mechanism, the shear wire would be replaced by a creep spring, and the delay would be standardised at 1/10 second. Thus fuzes No. 30 and 31 became identical, and the latter number was abandoned, the modified No. 30 being known as the Mark II.

By November 1935 supplies of the new fuze, although not entirely satisfactory, had been issued to overseas command. Experiments and trials to improve the waterproof sealing went on without much success until February 1939, when a device was finally agreed and approved.[5] Very few No. 30 fuzes were dropped in S.A.P. bombs in the Second World War, for in April 1940 they had been replaced by tail pistols.[6]

No. 34 and 37 fuzes for A.P. bombs

Another early type from the original fuze development programme was the No. 34. This tail fuze was designed for the 450 lb. armour piercing bomb, the main requirement being that it should provide a delay of 50 feet after impact with ¾ inch plate at a striking velocity of 700 feet per second.

[1] A.M. File S. 24467/1.
[2] A.M. File S. 24467.
[3] O.C. Memo. B. 24043.
[4] A.M. File S. 24467/2.
[5] A.M. File S. 24467/4.
[6] A.M. File S. 756870.

Design work began in 1924, but was later suspended until redesign of the bomb tail had been decided in February 1925. Experimental manufacture commenced in the following April. From a brief description at that time, it was a tail fuze, vane armed, and the delay was provided by pyrotechnic means.[1] Arming was affected by vane rotation freeing an arming spindle from an inertia pellet which allowed a small detonator to come in line with the pellet striker. On impact the pellet set forward, the flash from the small detonator ignited the delay composition, and this, after a set time, ignited the main detonator and magazine.

It will be noted there was no reduction gear in the early model, but in August 1926, after various static and air dropping trials, it was decided to fit some form of gearing to ensure a safety fall of 50 ft. Development went on until February 1930, when, after various failures and consequent redesign, the modified reduction gear was successful in tests at Martlesham Heath. Production should have commenced in June 1931, but was postponed until December of that year to await the manufacture of the bomb.[2]

Very few fuzes were in fact manufactured, for by July 1932 production of the 450 lb. armour piercing bomb had been cancelled.[3] Compared with some other fuzes, development of the No. 34 had been uneventful. Simple Air and Naval Staff requirements had made design work easier, and, although no service trials were done in A.P. bombs, the fuze was apparently accepted as satisfactory by all concerned.

With the introduction of the 2,000 lb. armour piercing bomb in 1936 a fuze similar to the No. 30, but larger, was produced and was known as the No. 37. Development and production was uneventful except for some trouble in providing a pyrotechnic delay of 1/10 second. This, as was to be expected, was inclined to be erratic, but was accepted pending a change over to pistol/detonator fuzing. The No. 37 fuze remained unmodified as the standard fuze for the 2,000 lb. A.P. bombs Marks I–III, but was little used, for the later type of bomb, the Mark IV, was equipped with pistol/detonator fuzing.[4]

No. 36 fuze for light cased (L.C. bombs)

Trials at Porton in December 1928 with chemical filled aircraft bombs pointed to the necessity for a means of bursting the bomb above the surface of the ground in order to get the most efficient dispersion of the filling.[5] A design for such a fuze was prepared, and placed before the Ordnance Committee[6]; but six years later, after further trials, it was ascertained that the bombs would have to be of the tail ejection type and a special fuze would be required,[7] with the explosive situated as far forward in the nose of the bomb as possible. If the fuze container projected into the bomb the liquid below the level of the container remained in the bomb and was thus wasted. The best results were obtained when the velocity of the bomb had been retarded and a delay of 1½ seconds to 2 seconds was required.

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[1] O.C. Memo. B. 7162.
[2] A.M. File S. 22763.
[3] D.C.A.S. Min. S. 17413, 28 July 1932.
[4] A.M. File S. 38532.
[5] A.M. File S. 27209.
[6] O.C. Memo. B. 17103.
[7] The fuze was required to develop sufficient gas pressure to blow out the welded tail end of the bomb and its liquid content without igniting the liquid.

Design of a suitable fuze was commenced early in 1935, and an order for experimental fuzes for the 250 lb. L.C. bomb was placed in October 1935. Difficulty was experienced in the provision of a suitable delay, and it was not until August 1936 that five bombs were dropped at Porton with satisfactory results (except for the magazine, which had insufficient power). Soon afterwards, however, it appeared certain that the fuze would need strengthening to be suitable for dropping on hard targets, and at a meeting of the Weapons Committee on 27 August 1936, it was agreed that this should be done. Towards the end of 1936 the delay required was altered to 0·5 second.

Early in 1937, when the fuze had been redesigned and a larger magazine fitted, manufacture was commenced. Bomb and fuze trials were carried out at Leysdown on 8 June 1937, but the bombs broke up before the fuze operated. By the end of 1937, a limited number of fuzes were ready for filling but, at proof tests, the delay was found to be well below the minimum required, and it was not until July that a satisfactory delay composition was found.[1]

Between 3,000 and 4,000 empty fuzes had been delivered to Woolwich by 11 October 1938, and supply was settling down to 400 per week. Trials at Porton during November and December revealed that the fuze was too weak, and modifications were suggested. Trials of the modified fuze were successful. A design incorporating the modifications was finalised in March 1939 and was designated fuze No. 36 Mark II (N.D.). It was a fuze of similar design but without the delay, and was introduced into the service at the end of 1941 for use in incendiary bombs, where the delay was not required.[2]

No. 38 fuze for L.C. bombs

In order to take full advantage of the carrying capacity of aircraft when small bombs were to be used, the Ordnance Board was asked in June 1936 to design a bomb and fuze which was not air armed, suitable for loading into small bomb containers.[3] It was nearly a year before the shape of the bomb was finalised, and in April 1937 it was decided to use an inertia pellet type of noze fuze which would incorporate a removable safety device for transit.[4]

The design of the fuzè to be permanently carried in the bomb was finalised in April 1938 and incorporated in its safety arrangements, a spring and a brass ferrule, designed to protect the detonator cap against being struck when the bomb was dropped on to concrete from a height of 7 feet. In addition, the striker of the fuze was withdrawn as far as possible for transport and storage, and, so long as the striker was in this position, it was impossible for the cap of the detonator to come into contact with the point of the striker. Four hundred fuzes were ordered with the first fifty off production to be used for trials.[5]

Rough usage and dropping trials at Woolwich proved the design to be successful and it was expected that fuzes would be ready for tests at Porton by August. Inert fuze trials indicated that the fuzes were satisfactory[6] and two months later successful trials were carried out with filled fuzes. By this time the 400 fuzes had been manufactured and were ready for filling.[7]

[1] A.M. File S. 34778.
[2] A.M. File S. 34778/2.
[3] A.M. File S. 27209.
[4] A.M. File S. 37570.
[5] A.M. File S. 37570/2.
[6] A.M. File S. 37570/3.
[7] A.M. File S. 37570/4.

Further trials at Porton in November 1938 indicated that the fuze would need strengthening for use against hard targets. Trials carried out in May 1939 gave satisfaction and a large order to manufacture this modified fuze, known as the Mark II, was placed.[1] It was not until March 1940 that the production fuzes were ready for tests against the hard target at Porton, for due to difficulty in obtaining the specified delay of one second, the specification was altered to a maximum delay of four seconds.[2] Ten bombs were dropped and their satisfactory functioning having been proved,[3] resulted in the introduction of a fuze of similar design, but having a smaller magazine for use in the 120 lb. smoke bomb, and was known as the No. 864.

The manufacture of the No. 38 Mark II fuze, was found to be a bottle neck in getting the 30 lb. L.C. bomb into the service and thus a fuze which was simple and easier to produce in large quantities was designed.[4] This fuze was to be known as the No. 846.

No. 846 and No. 879 fuzes for 30 lb. incendiary bomb (I.B.)

The No. 846 fuze consisted of a cylindrical body drilled centrally to accommodate an inertia pellet containing a detonator. Its sharp pointed striker was riveted to the nose of the fuze and protruded into the central hole in which the inertia pellet was held away from the striker by a creep spring. Safety for carriage in aircraft was provided by a ferrule which was safe for a nine foot drop on to concrete, while a steel ball, protruding into the central hole of the fuze and engaging in a cannelure in the inertia pellet, provided safety in transit. The steel ball was retained in position by a pin which was removed when the bomb was loaded into the container. The lower portion of the fuze accommodated the bursting charge. Trials, at A. & A.E.E. in May 1941,[5] indicated that the fuze was satisfactory against hard and soft targets, but further trials a month later, while confirming this, indicated that minor modifications were desirable and consequently information on the use of the No. 846 fuze in the 30 lb. incendiary bomb was not circulated to the service until April 1942.[6]

With a view to saving brass, manufacturing time and cost, some experimental fuzes were made in bakelite, but trials showed that the material was unsatisfactory and work was stopped in July 1942. Three months later ninety-six fuzes in special strengthened bakelite had been manufactured but, from the result of trials at A. & A.E.E.[7] in January 1943, the bakelite fuze proved to be unsatisfactory, and manufacture of the fuze reverted to brass.

The 30 lb. incendiary bomb having a modified gel filling, required a different explosive in the burster, and the No. 846 fuze was modified in October 1943 by the inclusion of coarse aluminium powder in the burster well in addition to the gunpowder. This fuze was known as the No. 879 and arrangements were made to have a large quantity of fuzes filled with the modified filling, but it was found that the detonator was not reliable in igniting the burster charge, and in March 1944 stocks were withdrawn from use. No further No. 879 fuzes were to be filled for the time being and the development of the new filling for the

[1] A.M. File S. 37570/5.
[2] A.M. File S. 37570/7.
[3] A.M. File S. 37570/8.
[4] A.M. File S. 37570/9.
[5] M.A.P. File S.B. 16235.
[6] M.A.P. File S.B. 16235/2.
[7] M.A.P. File S.B. 16235/3.

30 lb. incendiary bomb, for which the fuze was required, was stopped. At the end of 1944 the special fillings for incendiary bombs were no longer required and the fuze was declared obsolete.

Hydrostatic fuzes

Early in 1942 the Air Staff stated a requirement for a depth bomb with a higher explosive content than either existing anti-submarine bombs or depth charges, and which did not possess the operational limitations of the depth charge.[1] Fuzing was required to be hydrostatic and infinitely variable between 20 feet and 150 feet depth, also a device was to be incorporated, which could be operated by the pilot, to decrease automatically the basic depth setting. If it was considered that the above would unduly delay the design of the weapon, two alternative settings would be accepted. These settings were to be selected by the normal nose and tail fuzing system and be 25 feet and 50 feet respectively. In order to permit the weapon to be used as soon as the bomb was designed, a hydrostatic fuze, designed to fire at a depth of 25 feet, would be considered suitable as an interim measure. The fuze was to function reliably after release from any height up to 1,500 feet at speeds up to 250 knots. These requirements were subsequently amended—the height limit raised to 5,000 feet, and the requirement for selective or variable fuzing could be postponed.

No. 862 hydrostatic fuze

Twelve hydrostatic fuzes were ready for initial trials by July. They were of simple construction designed as a nose fuze, but eventually used in the tail. When water reached the fuze, it passed through entry holes and filled a space above a rubber diaphragm in the top part of the fuze. The water pressure forced the rubber diaphragm down onto the striker head which was held up by spring loaded striker levers. When the water pressure was enough to force the striker levers down past dead centre, the striker snapped sharply over. The detonator was carried in a sliding shutter which was held in the safe position by a spring. Hydrostatic pressure (under a water head of about 10 feet)[2] operating on rubber bellows moved the detonator shutter into the armed position.

Trials, which were carried out at the Marine Aircraft Experimental Establishment (M.A.E.E.) in November 1942, showed that the No. 862 fuze functioned unreliably when dropped from heights above 750 feet;[3] was liable to countermine, or sustain damage which would prevent functioning, even with "stick spacings" of 120 feet or more; and was liable to fire in the event of a dry hit.[4] An extended series of full scale static trials; reduced scale experiments; consultations with experts; experiments to prove theories existing on behaviour of underwater shock devices; and the development of a new technique[5] of carrying out countermining trials, led to the adoption of an anti-countermining chamber fitted with a quick acting valve. The design of this valve was the joint responsibility of the Chief Examiner Armament Design (C.E.A.D.) and the Royal Aircraft Establishment (R.A.E.)[6]

[1] O.B. Proc. 555.
[2] M.A.P. File S.B. 39180/1.
[3] M.A.P. File S.B. 37551/3.
[4] M.A.P. File S.B. 39180/2.
[5] A bomb with reduced charge of high explosive was used to permit drops from the air, and thus attain realistic conditions without danger to the dropping aircraft should countermining occur.
[6] M.A.P. File S.B. 39180/4.

The chamber anti-countermining was a cylindrical cast iron container which completely enclosed the hydrostatic portion of the fuze. A plunger type valve, incorporated in the top of the chamber, was designed to eliminate the effect of the pressure waves built up by the first and subsequent explosions when a stick of bombs was dropped. The fuze was located in the chamber by means of a locking screw which held it firmly in position. An automatic sealing valve was provided so that on withdrawal of the fuze safety wire, no water could enter the chamber except by way of the valve on top of the chamber.

Whilst this work was in progress, trials with an improved version of the No. 862 fuze showed that satisfactory functioning could be obtained with a stick of four bombs released from heights up to 5,000 feet.[1] A lower height limit of 500 feet was calculated to be safe in the event of a dry hit or countermining near the surface. Extensive trials were carried out to test the anti--countermining chamber and over 200 bombs were dropped to test this device. Further trials were carried out in attempts to prevent the fuze functioning in the event of a dry hit which was eventually prevented by the addition of a detent, and the modified version of the fuze was known as the No. 862 Mark II.

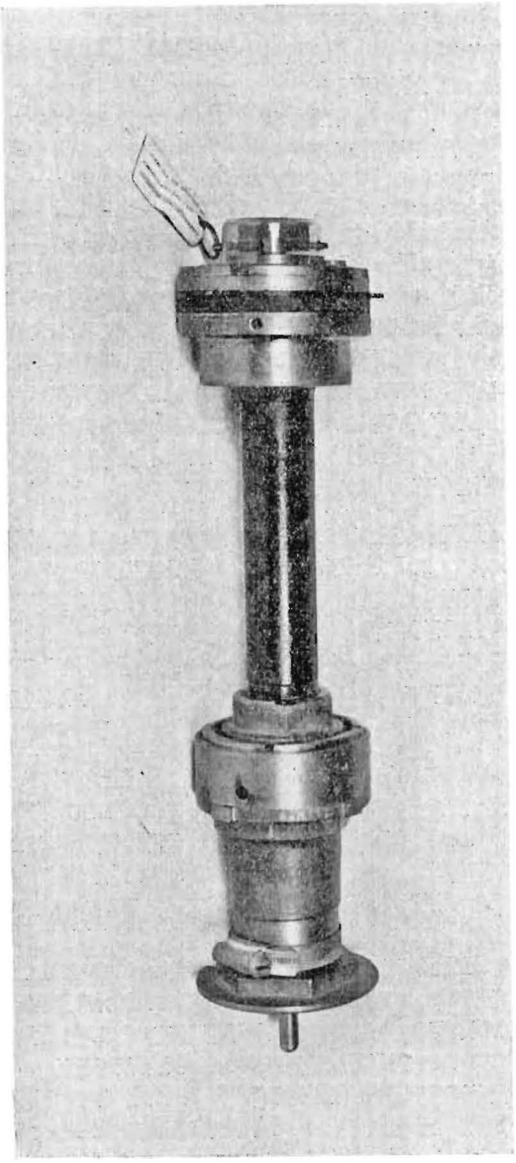
No. 875 fuze

The hydrostatic fuze which has been described did not fully meet the Air Staff requirement. During the trials of the No. 862 fuze, the Royal Aircraft Establishment (R.A.E.) were designing a fuze which would be nearer to the requirement, and in the early stages of development was referred to as the R.A.E. Hydrostatic Fuze.[2] By July 1943, twelve fuzes fitted to 100 lb. A.S. bombs had been dropped at Fairlie range with very satisfactory results, eleven of the twelve bombs dropped functioned at a depth of 19 feet. Trials with the fuze fitted in 600 lb. A.S. bombs in September, gave very consistent results as to depth of functioning, but there were six failures out of the thirty dropped from heights of 100 feet and 250 feet. At this time there were three types of fuzes No. 875 for use in various sizes of A.S. bombs. The fuzing caps were painted green, red or blue to indicate for use in 600 lb. A.S., 100 lb. A.S. and 250 lb. A.S. bombs respectively. Further trials in October 1943 from 300 feet and 1,000 feet resulted in one failure from 1,000 feet. These results were considered satisfactory and it was decided to proceed with trials to test countermining.

Ten sticks of two bombs each were dropped in December with a spacing of 120 feet ; in all sticks the second bomb either failed or was countermined, but none fired shallower than 20 feet.[3] Owing to the high failure rate the trials were suspended to investigate the cause of the failures. These were carried out by dropping sticks of two bombs, the first bomb being filled H.E. ; the second was a buoyant bomb fitted with one or more ' target ' fuzes. Five sticks were dropped, the buoyant bomb recovered and the fuzes examined ; all the live bombs had fired but half the target fuzes failed, due to the striker having fired before the shutter could move across to the fully armed position. To overcome this trouble it was proposed to fit a duralumin shutter and a stronger shutter spring ; at the same time R.A.E. proposed a rotating shutter. Trials in January 1944, with the lighter shutter and stronger spring gave

[1] M.A.P. File S.B. 37551/6.
[2] M.A.P. File S.B. 62064.
[3] M.A.P. File S.B. 50710.

better results—one failure in ten drops.[1] In the same month seventy No. 875B fuzes were modified to include the rotary shutter and were known as the No. 875B Mark II. The modified fuze was later known as the No. 895B Mark I.[2]



DEPTH CHARGE PISTOL, MARK XX

No. 895 fuzes

The No. 895 fuze was similar in principle to the depth charge pistol, but on a smaller scale, and incorporated an inertia lock to confer immunity from shock operation. Water entered the fuze through small metering holes fitted with anti-countermining valves. The hydrostatic pressure was applied to rubber

[1] M.A.P. File S.B. 50710.
[2] M.A.P. File S.B. 56749/1.

bellows, which, operating via a ball catch, lifted the striker and compressed the firing spring. At the same time an extension on the striker assembly rotated the cylindrical detonator shutter into the firing position. When the firing spring was compressed the retaining balls fell out and the spring forced the striker down on to the detonator. To prevent the fuze functioning by inertia if the bomb hit tail first, there was a light quick-acting inertia-operated sleeve which moved balls in front of the striker to prevent its motion.

Preliminary trials, carried out by the Marine Aircraft Experimental Establishment (M.A.E.E.) in May 1944, showed that the fuze functioned very reliably and consistently in single drops from low heights when used in the 600 lb. A.S. bomb, the average depth of functioning being 32 feet. The next month eighteen bombs were dropped from 5,000 feet, but there were eight fuze failures.[1] Investigation of the failures was made in the same month by dropping buoyant bombs, each fitted with four target fuzes.[2] Twenty-eight fuzes were dropped and there were twenty-three failures. When the fuzes were stripped and subjected to critical examination, it was found that there was an excessive amount of friction between the impact lock and the striker, and it was considered that this was the cause of the high percentage of failures. Fuzes in which this excessive friction had been eliminated were dropped in H.E. filled bombs in July 1944. There were six failures in the thirty bombs dropped, but the firing depth remained very consistent. The next month twenty fuzes which had the impact lock removed, were dropped from 5,000 feet, there was only one failure. As it was not desirable from the safety aspect to remove the impact lock, the next trials were carried out with a stronger impact lock spring and eighteen bombs were dropped with no failures.

The countermining trials which followed proved disappointing ; in sticks of four bombs dropped by M.A.E.E. in October 1944, as many as three bombs countermined, although not at a dangerously shallow depth. The Royal Aircraft Establishment (R.A.E.) evolved a comparatively simple modification from suggestions of the Director of Armament Development (D.Arm.D) and M.A.E.E. If the modification was successful, it was to be incorporated in a new design of the No. 895 fuze which would also include a centrifugal air arming device. Trials on the No. 895/30 Mark I were successfully completed at the end of 1944, and Air Staff approval was requested for its use in the 600 lb. A.S. bomb in releases from 50 ft. to 5,000 feet and at all speeds up to 250 knots.[3] Towards the end of 1945, the 600 lb. A.S. bomb, for which the fuze was designed, was declared obsolete and production of the fuze was stopped.[4]

No. 900 fuze for aircraft mines

Towards the end of 1944, a delay type nose fuze for use in aircraft mines was required.[5] The Ordnance Board were requested to instruct the Chief Engineer Armament Design (C.E.A.D.) to proceed with the preparation of a design to meet the following main requirements :—

(*a*) To cause detonation of a mine laid from aircraft should it fall onto land, mud or into water of a depth less than that specified as a minimum in which the mine was to become active.

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[1] M.A.P. File S.B. 56749/1.

[2] The bombs were made buoyant and floated on the surface after being dropped making recovery and examination of the fuzes possible.

[3] M.A.P. File S.B. 62604.

[4] M.A.P. File S.B. 56749.

[5] M.A.P. File S.B. 60873.

(*b*) A delay period of twelve seconds minimum between impact and detonation to enable the fuze to be used in low level attack.

(*c*) The design must be such as to ensure complete safety to the laying aircraft under all conditions.

(*d*) Must be capable of being dropped ' Safe '.

The fuze developed caused the mine to function as a bomb if it fell on land or into water of a depth of less than six feet. It was ' cotton-reel ' armed and contained a clockwork delay mechanism while a shuttered detonator was operated by hydrostatic pressure.[1] The cotton reel method of arming was only to be incorporated in the design for use during trials to test other features of the design as, in the event of the mine falling off an aircraft with the fuzing inadvertently set ' live ', it would certainly detonate fifteen seconds after hitting the ground.[2]

Six 1,000 lb. Mines 'A' Mark VII fitted with the fuze were released into the wall target at the Aircraft and Armament Experimental Establishment (A. & A.E.E.), but the results were disappointing; only one bomb functioned correctly, but in all cases the cotton reel arming appeared to have functioned correctly. When the fuzes were examined, two possible causes of failure were present, and the design was modified and air arming incorporated. Twelve fuzes were prepared, six having cotton reel arming to test the modifications made, and the other six to the new design with air arming. Trials of the fuzes with cotton reel arming were satisfactory when dropped against the wall target, but in all cases the mine body completely disintegrated.[3] In these circumstances detonation of the H.E. filling was unlikely to be obtained and there would be a possibility of premature ignition of the filling.

In view of these results it was considered that the tests against the wall target were too severe and were not representative of the hard surfaces in the immediate vicinity of harbours and the like.[4] The Director of Torpedoes and and Mining agreed with this view and that it would be sufficient if the fuze fired when it hit a target which did not wreck the whole mine. Trials of the air arming mechanism were a failure; six mines were dropped, none of the fuzes armed and at the end of 1945 the requirement for the fuze was suspended. Trials to clear certain problems which had occurred during the development of the fuze were to be carried out, but on low priority.

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[1] In this design a static line attached to the aircraft was wound round a reel. When the bomb dropped the reel was rotated unscrewing the arming rod.

[2] O.B. Proc. 02785.

[3] M.A.P. File S.B. 60873.

[4] O.B. Proc. Q. 3385.

CHAPTER 18

FLARE FUZES

Pyrotechnic delay fuzes

No. 28 Nose Fuze

The No. 28 Nose Fuze was designed and produced solely for use in Reconnaissance Flares and Photo Flashes. It would seem to have originated about 1924–1925 as a requirement for the 4-inch reconnaissance flare and initially, made use of a ' pull percussion ' igniter operated by means of a lanyard attached to the aircraft, and in this manner was both armed and fired on release. The igniter worked in conjunction with time-burning rings, similar to the old type used in the Army shell fuze, and this combination, after a pre-set delay, fired the magazine, ejected the parachute, and ignited the flare composition.

The great disadvantage of this fuze was the danger that it could be accidentally fired whilst still on the carrier, and a replacement, which could be air-armed was essential. Early references quote the modified No. 28 as being under development in 1927 ;[1] it was probably first used in the Service about 1930 and incorporated many much needed modifications to the previous pull percussion type. The main modification, to overcome inherent danger, was the incorporation of a firing-rod which, attached to a fuzing link, allowed the fuze and flare to be ' safe ' on the carrier and also, by its removal or retention, selective dropping—' live ' or ' safe '.

On ' live ' release the firing-rod was withdrawn and remained on the carrier allowing a spring-loaded pellet to carry a detonator on to its striker. The detonator ignited two delay composition rings, one above the other, each capable of being pre-set for a given burning time, thus, until the lower time ring had burned for the set time, the magazine could not be ignited, and only then after a valve had been lifted by the screwing out of a wind-operated arming spindle. Time settings ranged from zero to 22 seconds with a ' safe ' setting for storage and handling. In a mechanical sense this was a reasonably efficient fuze, but like any other pyrotechnic was liable to be affected by climatic conditions and consequently required very careful supervision in storage and use.

Soon after its introduction into the Service the fuze was found liable to fail from two main causes :—

(*a*) The arming spindle screwing right out and providing an opening for air to enter and ' kill ' the flash to the magazine.

(*b*) Over short delay settings the flash to the magazine occurred before the arming vanes had had sufficient time to lift the valve.

To remedy these faults, a Mark II version was produced in 1933 with the delay settings of 0 to 4 seconds, replaced by a minimum setting of ' 7 ' to obviate the risk of ' blinds ' occurring below that figure.

An excessive failure rate of the No. 28 fuze, reported mainly by flying boat and sea-shore based squadrons, had by September 1934, been the subject of many investigations and trials, from which it was concluded that failures were

[1] O.B. Annual Report 1927, p. 75.

chiefly due to dampness entering the fuze mechanism and causing a corrosion of working parts, and/or deterioration of the explosive content. There were other suspected causes, including misuse by Service units, but generally the main troubles appeared to be climatic. In that month therefore the Deputy Chief of Air Staff ordered that the fuzes were to be expended in air exercises and that by the time these stocks were exhausted, a more satisfactory fuze would be available. The development of a replacement was in hand as an 'urgent matter,' but, like most other armament development of that period, was a long and tedious affair, and the No. 28 continued in service for many years.[1]

By April 1936 the fuze had been modified to improve its mechanical performance, and it had become the practice whenever possible to send all fuzes which had been carried once on flying boats back to Woolwich for refilling. It had originally been intended to declare the No. 28 obsolete when its replacement (No. 35) had proved satisfactory, but protracted difficulties in development and production, as well as a change of policy regarding the use of flares, led to the reinstatement of the No. 28 as a suitable fuze. By 1929 R.A.F. aircraft were, however, carrying flares internally, for launching through flare-chutes, and in consequence the poor waterproof qualities of the fuze ceased to be a major consideration. In fact, large numbers were then being ordered as the No. 35 had proved unsafe for chute launching.[2]

The use of the fuze with Photographic Flashes during 1940 brought forth two improvements affecting both the pyrotechnic contents and the arming vane mechanism (reduced in diameter to prevent damage on leaving the launching chute). At the suggestion of Bomber Command, two further improvements had been completed by July 1941. These were both external and consisted of a black and white setting scale, positioned over the normal engraved scale, and a small threaded positioning screw; the new setting scale was graduated to indicate the height at which the fuze would operate and was an aid to easier reading.[3] The second improvement overcame the necessity for using two fuze-setting spanners, which could easily be lost in the aircraft.[4]

In October 1941 the photoflash was required—for photographic reasons—to explode at 0·4H below the aircraft (H being the height of the aircraft) instead of 0·55H for which the new scale had been made. Research and experiment up to 1942, to calibrate the new height scale setting, culminated in February 1942 with a new scale, but it is perhaps worth while mentioning that in any event the practical result, due to the use of a pyrotechnic fuze, could only ever be approximate. From late 1942 production of the fuze had ceased, stocks were being rapidly used up, and the fuze was finally withdrawn from service on its replacement in March 1943 with the No. 848.

No. 35 Fuze

This fuze, already mentioned in the forgoing account, was in fact an alternative and not a replacement for the No. 28, as for reasons to be given later, it never entirely superseded that fuze. Development commenced in 1934 when the fuze was known as 'watertight time fuze for parachute flares.' At the outset it

[1] A.M. File 222026/32.
[2] A.M. File 585253/36.
[3] M.A.P. File B. 140128/40.
[4] By the latter part of 1941 almost all flares and photo flashes were launched from chutes. These were armed with the No. 28 fuze set 'safe' on take-off—and reset for the required operational bursting height when near the target.

appeared to show great promise ; it was fitted with pyrotechnic delay of from 4 to 17 seconds, but was not vane armed ; to ensure air and watertightness the whole of the working portion of the fuze was completely enclosed in a metal cover which was only removed for setting the required delay.

Thus the safety factor provided by air arming was not included, but the Superintendent of Design considered that this was well provided for by a fixed delay of 4 seconds after release ; he also mentioned that a hang-up on the carrier, due to the firing mechanism remaining connected to the fuze, was most improbable.[1] On release, the fuzing wire withdrew a firing-rod fitted with steel balls to retain it to the striker and keep the latter in a ' safe ' position.

The action of ' pull off ' compressed the striker spring to a degree which finally released the balls, allowing the striker to spring forward and fire a detonator ;[2] then followed the normal time-ring burning until expiration of the pre-set delay and, finally, ignition of the magazine. The usual safety devices for transit and handling were included, but it will be apparent that anything short of complete release (fuze ' Live ') represented a serious danger to aircraft and crew.

Development and static tests, and the first air trials, held at Martlesham Heath in January 1936, although fairly successful, showed the need for several improvements.[3] In the following June, therefore, ten improved fuzes were sent to the Marine Aircraft Experimental Establishment at Felixstowe, and were tested, between July and September, by long exposures on flying boats to rain and salt water spray, both at moorings and in flight, before eventually dropping.[4] These trials and others in progress at Coastal Command Stations were noted as satisfactory by a Department of the Directorate of Armament Development.[5]

It was recorded that the new fuze was not as safe as the No. 28 due to the abandonment of the arming vanes which prevented the fuze being watertight. The possible danger of flare ignition should the nose drop from the carrier in flight was commented on, and was to be investigated by air trial when more experimental fuzes were available. Meanwhile it was recommended that production orders should go ahead.

Service trials were successfully concluded at Mount Batten and Calshot between November 1936 and January 1937, and in the latter month production manufacture was arranged.[6] By the following July, however, the launching of flares from chutes had become a necessity, and although at that time no fuzes had been issued to the Service, arrangements were made for a number from the first batch to go to the Royal Aircraft Establishment at Farnborough for flare chute tests.

Various small modifications were introduced from time to time, and in June 1938 instructions for its use were issued ; these included some very specific details as to rigidity on the carrier and other safety measures necessitated by the manner in which the fuze was armed and fired. Considerable stocks existed by January 1939, when the important change to chute-launched flares was well

[1] Nevertheless a dangerous possibility with a fuze armed at the moment of release.

[2] The ' pull off ' was about 5 lb. with a small movement to arm and fire the fuze which was, in fact, fired on release.

[3] A. & A.E.E. Report M/Arm/4551/1 in A.M. File 318419/34.

[4] M.A.E.E. Report F/Arm/35 in A.M. File 318419/34.

[5] RD/Arm.2 then in the Air Ministry, transferred in 1940 to the Ministry of Aircraft Production.

[6] A.M. File 318419/34.

under way.[1] Apart from old type aircraft, and those of the Fleet Air Arm which could still carry flares externally, the No. 35 fuze was virtually out of the Service for two main reasons :—

(*a*) Reliability of firing from chutes was open to question ; and

(*b*) Even if this was made satisfactory the fuze was too dangerous to be used from the aircraft's interior.

In the period to August 1939 constant investigations and trials were carried out to perfect the various types of aircraft flare chutes, as well as a means of using the No. 35 fuze, and although flare launching became very efficient only moderate success with an adaptor and lanyard system was achieved with the fuze.[2] So, except for limited use with the 4·5 inch flares in certain aircraft, the fuze was but little used with flare chutes, and was almost exclusively used with carrier-borne flares.

In January 1940 Coastal Command reported two accidents with the fuzes due to accidental release from carriers on stationary aircraft. Whilst appreciating the danger of the fuzes, and commenting that the strictest warning had been given to personnel handling them, the Command considered that some extra safety device was necessary. The Directorate of Armament Development replied that it was not possible to provide this extra safety device, but trials of a reliable replacement were taking place. Meanwhile, if the existing official instructions for use—augmented by Command orders—were adhered to, such accidents should not occur.[3]

In March 1940 A. & A.E.E. reported a similar accident, in this case due to a defective flare chute. At the same time they emphasised the constant danger with the fuze if by any means they were accidentally fired. The final paragraph of the report recommended that ' Any form of flare fuze must be provided with an air vane device, and fuzes without such a device possessed an entirely inadequate margin of safety.'

A replacement was still undergoing trials in June 1940 when the Mark II version of the No. 35 Fuze was being manufactured and, on its introduction into the Service, the Mark I fuze was declared obsolete. This latter fuze differed only from the Mark I in that the burning time was increased to 22 seconds and the setting ring was graduated in thousands and hundreds of feet. By the following August photographic flash bombs carried on bomb carriers and fitted with the Mark II fuze were in use. Various accidents had been reported, and in that month, in an effort to prevent such occurrences, trials were held by A. & A.E.E. with the lanyard adaptor (as used with the 4·5-inch flares from chutes), on fuze release from carriers.[4] These trials were very successful and the opinion was given that the lanyard greatly increased the safety of the fuze on carrier release with the result that it was ordered to be generally used.[5]

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[1] A.M. File 622983/37.

[2] When dropped from a carrier, the fuze received a direct pull to arm and fire. When launched through a chute (tail down), this pull could not be obtained without some conversion or adaption of chute and/or fuze.

[3] M.A.P. File B. 69856/40.

[4] M.A.P. File B. 110116/40.

[5] By this method the fuze firing-rod was protected from accidental contacts, and on release, allowed the flare to fall 6 feet before the fuze operated.

The supply situation in March 1941 was summarised by the Director of Armament Production in a minute to the Director of Equipment. The position was, that the No. 35 was the only fuze then in quantity production for flares, and existing contracts with five firms would all terminate by the following July. It was impossible to forecast when the No. 41 would be ready for issue and another alternative (No. 42) could then only be produced at the rate of 1,000 per week.

Further contracts were placed in the following month and manufacture continued until October 1941 when it was finally cancelled. By September 1942 the fuze was out of service except for Fleet Air Arm use, and for the purpose of this account the development story ends.[1]

As a replacement for the No. 28 it was not a success, its watertight qualities were rendered comparatively unnecessary by the advent of chute launching, though it was truly essential for flares on external carriers. Its potential danger, not being vane armed, far outweighed its reliability to operate, so it was naturally viewed with mistrust by operational users, and, but for the delay in producing a suitable replacement, its service life would have been a great deal shorter.

In August 1940 a sample fuze, designed and produced by Messrs. Aladdin Industries of London, had been seen by D.Arm.D.'s representative and the firm had agreed to prepare drawings and include some small modifications, following which one hundred experimental fuzes would be ordered for trials.[2] It was then known as 'Emergency Flare Fuze', later the No. 42,[3] and offered great prospects in simplicity of design, ease of manufacture, cheapness and reliability, and the firm were asked to prepare for the production of 5,000 fuzes after the experimental trials.

Briefly it was a fuze needing no pyrotechnic filling, delay being provided by Bickford Safety Fuze. The base was made from a standard flare nose plug which became the container for a magazine of gunpowder, easy removal of the upper half of the fuze from the base was made by a simple bayonet joint, the base of the upper half being dome shaped to contain a brass delay capsule. Screwed into the dome was a tubular 'throat' containing a simple pull percussion mechanism, percussion cap, and a safety pin.

Originally five different delay capsules were scheduled for supply with each fuze, each capsule containing a different length of Bickford fuze intended to give the correct delay for release heights of 3,000, 4,000, 6,000, 8,000 and 10,000 feet. The fuze could be used with either internally stowed or carrier-borne flares; with the former the required capsule could be fitted a short while before release, with the latter the delay would obviously have to be fitted before take-off. Pull percussion was effected by dropping when a spring-loaded striker was released from its locking-balls by the pull of the fuzing wire. The consequent flash from the percussion cap ignited the time fuze which, on completion of burning, fired the magazine.

The considered advantages in design and production have already been mentioned, its probable operational disadvantages: (*a*) not waterproof, (*b*) not continuously adjustable, (*c*) not air-armed, to quote the Director of Armament

[1] M.A.P. File B. 110116/40/2.
[2] M.A.P. File B. 141703/40.
[3] M.A.P. File B. 141951/40. The intended replacement, the No. 41, was developed and produced in small quantities but not issued for service use.

Development (November 1940), were to be tested in service trials of the first experimental models. In September 1940 a ground test, simulating chute launching from aircraft, was held and apart from some trouble with percussion caps[1] the fuze was mechanically successful, delay times being particularly satisfactory. Two methods of firing the fuze were tried :—

(a) Direct lanyard attachment from fuzing link to striker.

(b) An ' all-ways ' pull percussion mechanism.

After discussion between the firm, the M.A.P. representative and the Chief Superintendent of Design, the latter method was adopted for each of manufacture and inspection.

Following this promising ground test air dropping trials were done at Boscombe Down (A. & A.E.E.) later in the month, and in the meantime Messrs. Aladdin carried out an experiment to test the waterproof qualities of the fuze. Two were left exposed to wind and rain for 36 hours, one being eventually submerged about a quarter of an inch in water. Both fuzes fired on test and, whilst the conditions were not as severe as might be encountered on a bomb-carrier, it did seem another promising aspect of the fuze. The air trial however was not successful, a large percentage of failures occurring due to the ends of the safety fuze being varnished ; the obvious alteration rapidly followed and by the end of October 1940 further ground and air trials had proved the fuze satisfactory.

The next step was to hold service trials in Bomber Command ; a number of experimental fuzes were sent to various stations to be carried in small quantities additional to the normal operational flare load. To assist in obtaining information on fuze performance, it was suggested that the trial flares should be dropped over the sea with various delay capsules ; opportunity for careful observation would be more easily available under those conditions than under those in the target area.

By December 1940 the production policy for the first 5,000 fuzes had changed, for although being made they would not be issued until the results of the Bomber Command trials were known. A detailed report was submitted by the Command on 22 December, all the points called for being favourably mentioned, in fact there was considerable enthusiasm over the fuze and it was recommended for manufacture as an interim measure pending the production of the No. 41. Within a few days further orders were placed, and, on the suggestion of the Directorate of Armament Development, a scheme to avoid waste of delay capsules was to be tried. This was to send out each fuze with one capsule only and to produce them in proportion to probable service consumption.

To cope with the increased orders, the firm slightly re-designed the fuze for mass production, and in January 1941, following the waiving of the Air Staff requirements for air-arming, the Mark I fuze was approved for service use. By that time arrangements were already in hand to produce a Mark II design which would include : several aids to waterproofing, a better locking device to screw the top half of the fuze to the bottom, and a spring-loaded shutter (moved aside when a capsule was fitted) to prevent prematures if a flare was released without such a capsule being fitted.[2]

[1] At that time the firm were using caps extracted from 12-bore cartridges. These were too powerful and arrangements were made for I.C.I. to supply some with a less violent composition.

[2] M.A.P. File B. 141703/40.

By mid-January 1941 the No. 42 Mark I Fuze, 15,000 of which were in production, were being issued to the service and were very successful in operations. Meanwhile drawings of its successor, the Mark II, were in preparation and by 22 March 1941 a quantity was ready for trial, all the proposed improvements on the Mark I having been included. About this time Bomber Command requested that delay capsules for heights of 14,000, 16,000 and 18,000 feet should be provided. In dealing with the flare and fuze situation generally, the command requested that sufficient No. 42 fuzes be made available to meet the whole operational requirement and thus abolish the use of the No. 35 fuze.[1]

Air trials of the Mark II, at A. & A.E.E. on 25 April 1941, were a complete success, twenty flares, ten from carriers and ten from chutes, were dropped and all fired satisfactorily. The fuzes tested were not fitted with a safety shutter but all other modifications (the Mark II was virtually a modified Mark I) were suitable and it was thought to be a great improvement on the earlier mark.

The trials were sufficient to warrant its introduction for service use with the provision of two delay capsules per fuze in the same total proportions as before. By September, the capsules for the increased heights were being produced and the Mark II fuze continued in service use in flares, not photo flashes, until early 1942, when it was replaced by an air armed type (Mark III and IV), afterwards known as the No. 848. Apart from a few failures, the No. 42 Series gave good service and was an efficient and popular fuze.

No. 848 Fuze

The only fuze considered safe for use in photo flashes was the No. 28B, but owing to its complicated construction, could not be produced in anything like the required quantities.[2] Aladdin Industries Ltd. were asked to increase the safety of the No. 42 Fuze by the introduction of an air arming device. They were asked to produce a fuze which :—

(*a*) Would not ice up when carried externally.

(*b*) Would function at an air speed of between 50 and 60 m.p.h. to meet the requirements of the low speed aircraft used by the Fleet Air Arm.

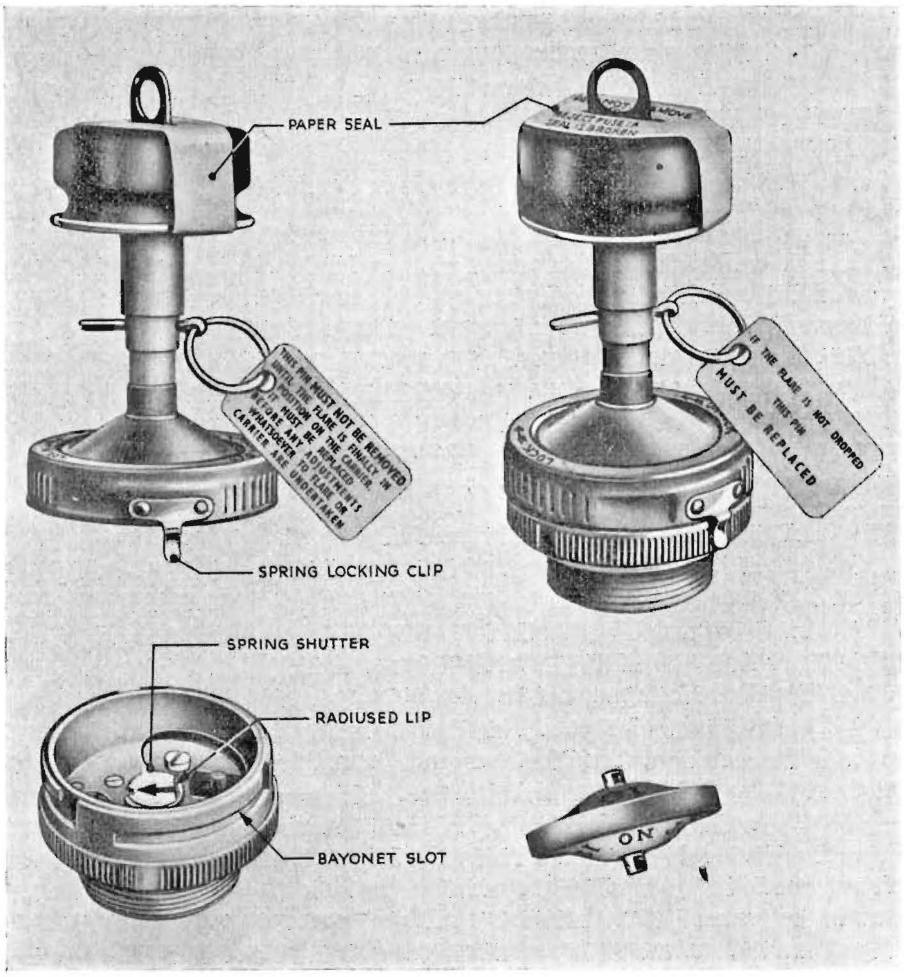
By the beginning of April 1941 they had developed a fuze with a small arming vane and a cap to prevent icing up, and, of the twenty tested at Boscombe Down,[3] there was only one failure ; service trials, with 44 fuzes, were completely satisfactory.

In the autumn of 1941 the number of flare fuzes required reached a figure of 20,000 a week and at the same time the No. 848 Mark I (new nomenclature of No. 42 Mark III designated in September) was introduced into the service for use in photographic flashes only. Trials carried out in November 1941 on redesigned cones to facilitate manufacture were satisfactory and production was commenced. The redesigned fuze was known as No. 848 Mark III.[4]

In the early months of 1942 flares fitted with the fuze were failing to ignite, and after extensive trials the reason was attributed to a supply of too violent firing caps. Closing three of the four holes in the striker socket, however, remedied this fault and a clip was provided for this purpose.[5] The fuze was

[1] M.A.P. File Res. Arm. 535.
[2] M.A.P. File Res. Arm. 726.
[3] O.C. Memo. B. 11842.
[4] M.A.P. File Res. Arm. 726/2.
[5] M.A.P. File Res. Arm. 726/3.

regarded with some suspicion by aircrews and cases were discovered where the flares and flashes were being dropped with safety pin in position. Investigation at one Group however, who were obtaining persistently good results, revealed that a double lanyard was used ; this allowed the safety pin to be left in position and withdrawn by the lanyard when clear of the launching chute or carrier.[1] This information was circulated to the service in December 1942.[2]



No. 848 Fuze Mark V with Typical Delay Capsule

Further trials were carried out at A. & A.E.E. between 27 February and 19 March 1943 to clear the latest mark of fuze (the Mark VA).[3] Forty-five fuzes were dropped, fifteen from each of the manufacturers, and there were four failures. From the results of the trial it was concluded that :—

> ' In view of the presumed necessity to use these fuzes in the Service to meet the present high demand, the modifications incorporated in current

[1] M.A.P. File Res. Arm. 726/5.
[2] M.A.P. File Res. Arm. 726/6.
[3] M.A.P. File Res. Arm. 726/7.

production may be considered acceptable. They must be considered as a " stop gap " until alternative fuzes are available and the fuze must not be treated or called " air armed ", and the removal of the safety pin must be considered as initiating the fuze.'

At the end of 1943 the No. 848 fuze was declared obsolescent in favour of the No. 849.

No. 849 Fuze

A fuze with an infinitely variable capsule was an urgent requirement for use in photographic flashes, and in August 1941 Aladdin Industries had developed a fuze in which the adjustment of the delay was carried out by turning the body of the fuze. The air arming device was similar to the one used in the No. 848 fuze which had already appeared for service use.

Preliminary trials at the Royal Aircraft Establishment were disappointing, and, in order to speed up the trials, it was decided to carry out tests of the capsule only, in a fuze with a pull percussion striker. Further trials at A. & A.E.E. on 10 September 1941 indicated that the fuze was unsatisfactory in its existing form and Messrs. I.C.I. Ltd. were asked to develop a lead covered fuze for use in the variable delay capsule. In October 1941 seven flashes were successfully dropped at A. & A.E.E. but the fuze was re-designed early in 1942, with a view to simple production in the large numbers required.

An arming mechanism, identical with that used with the No. 848 Mark III, was incorporated in the redesigned No. 849 but, although the requested lead covered delay was supplied, its mode of operation was varied. Briefly, the minimum time of delay was supplied by a short fixed length of fuze, the flame from which ignited a further length wrapped round a wheel ; as this fuze burned, flame was ejected at right angles to the circumference of the wheel and after a pre-set period, achieved by turning the wheel to the required position, ignited a powder pellet, housed in the base of the fuze, and this caused the magazine charge to be fired.

Production of the redesigned fuze, which was calibrated in aircraft height, soon followed and, of the eleven tested at A. & A.E.E. in August 1942, there was only one failure.[1] Service trials, using the double lanyard for launching, were entirely satisfactory and, in view of changing policy regarding the ignition height of photographic flashes, it was decided that the scale of the fuze be divided into 100 divisions[2] and a fuze setting chart provided for use according to whether the fuze was fitted to a photographic flash, reconnaissance flare, or any other type.

Early in 1943 an air arming mechanism was designed which it was hoped would increase the safety of the fuze. The arming vanes rotated an electric generator which produced current to fire a cap and delay fuze. Although the fuze was satisfactory it was found that the addition of an electric generator did not materially improve the safety of the fuze and development work stopped.[3] At a meeting in May 1943, to discuss pyrotechnic fuzes, it was agreed that, although the No. 849 met service requirements, no further modifications should be considered and that the design department should devote all its energies to an entirely new fuze.

[1] M.A.P. File S.B. 18913.
[2] M.A.P. File S.B. 18913/2.
[3] M.A.P. File R.A. 3638.

Barometric fuzes

The Ordnance Board was requested in October 1941 by the Director of Armament Development, to consider the development of a fuze which was barometrically controlled.[1] No requirements had been stated for a fuze to enable flares to be used from above 20,000 feet, but a future requirement was foreseen for a fuze for use in operations up to at least 30,000 feet. The irregularity of combustion at low pressure, and the possibility that flares of different ballistics might be introduced, made it doubtful whether modification of existing combustion type time fuzes, such as the No. 848 or the No. 849, was the best way of meeting the requirement.

The suggestion that a barometrically controlled electrically fired fuze might be developed, had been made in July 1941 by the Design Department, but at that time the Air Staff decided that there was no requirement for such a fuze.[2] Some experiments had been made by Messrs. Aladdin Industries, on their own initiative, on the application of a barometric control to a mechanically fired fuze. The Director of Armament Development visited the firm, and with a comparatively crude experimental arrangement, both types functioned within a time limit which would be equivalent to an accuracy of plus or minus 100 feet, and in some instances plus or minus 30 feet. The Ordnance Board considered it preferable that, since they differed fundamentally in principle, the two types of fuzes should be developed independently.

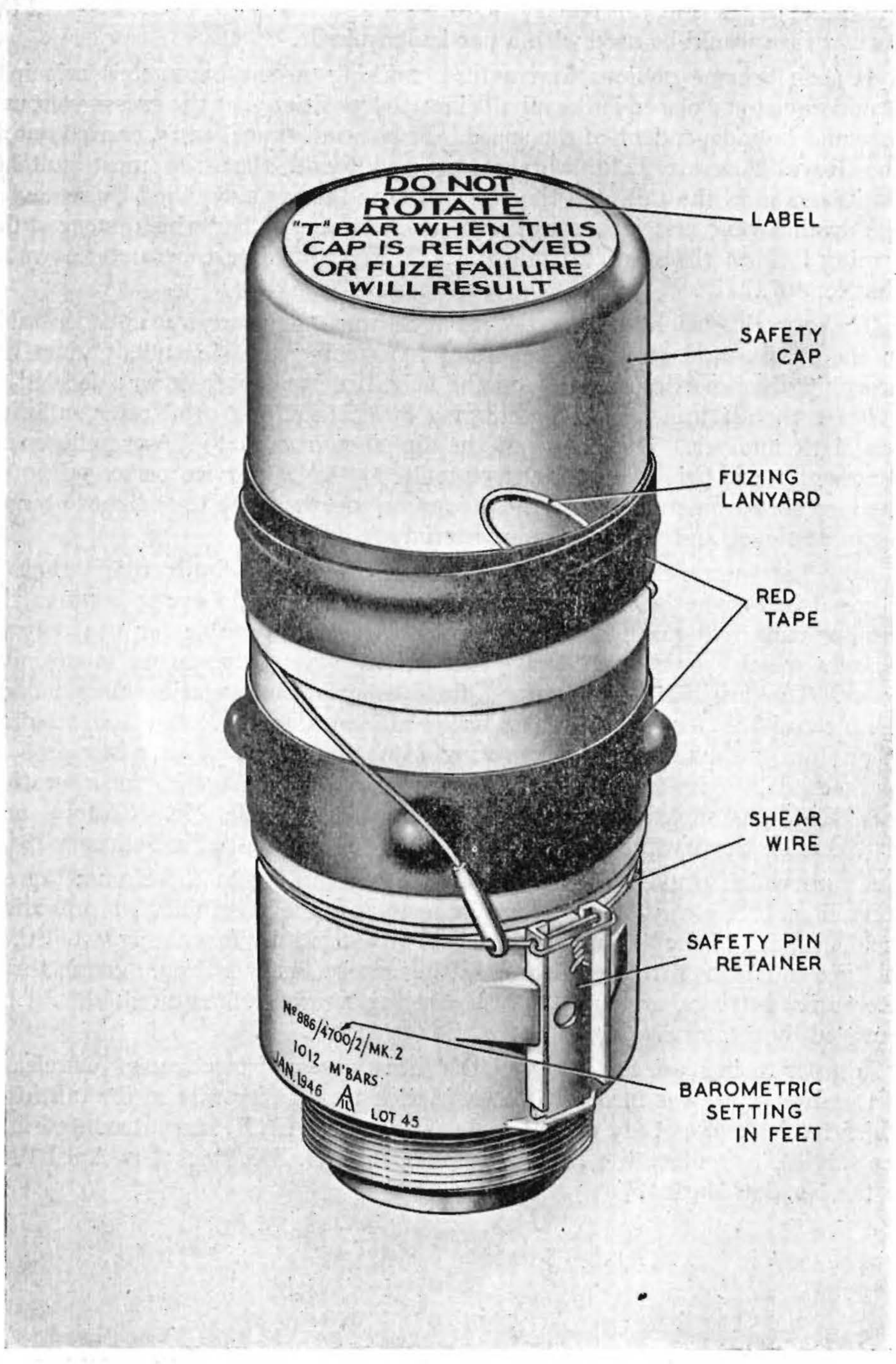
The fuze developed by Messrs. Aladdin Industries consisted of exhausted corrugated copper bellows fitted with a fixed stop at the lower end, and a flat platform at the upper end on which the spindle of a No. 848 fuze arming vane rested. On release from the aircraft, the arming vane unscrewed and allowed the bellows to contract at a regular rate, due to the increasing atmospheric pressure, and withdrew a taper pin from its position between three steel balls which were resting against a slightly conical tapering sleeve. As soon as the taper pin had been sufficiently withdrawn from between the three balls, a cocked striker was released and fired a cap which in turn ignited the magazine.

Early in 1942 the first fuze was completed and set to operate at 4,000 feet. Two flares were prepared, one fitted with the barometric fuze and one with a No. 42 fuze, and, so far as could be assessed by the aircraft and ground observers, the two flares operated within 250 feet height of each other. This was believed to be the first barometric fuze to be dropped from an aircraft and from its success, trials were to be carried out.

A trial was carried out, at A. & A.E.E. in February 1942, in which two 250 lb. incendiary bombs, fitted with barometric fuzes, were dropped ; both functioned satisfactorily at about 2,000 feet above the sea. The fuze was submitted for approval in July 1942 and was known as the No. 860 Mark I. Further trials at A. & A.E.E. and in Bomber Command were satisfactory and an experimental requisition for 1,500 was placed to meet immediate requirements. The first four production fuzes were tested at A. & A.E.E. early in August 1942 and all functioned satisfactorily.

It was not until March 1943 however, that the No. 860 fuze reached the quantity production stage. The initial development model was known as the Mark I, and had the body manufactured in two diameters, whereas the production model had a parallel sided body, and incorporated a spring loaded safety pin which flew out when the fuze was clear of the aircraft.

[1] M.A.P. File S.B. 32016.
[2] M.A.P. File S.B. 33543.



No. 886 Fuze, Mark II

Owing to the fact that a falling body sets up about itself areas of static pressure, according to its shape and speed of descent, it follows that a fuze constructed on the barometric principle will not work equally accurately in weapons of different shape. For this reason the fuze bodies were colour banded so that the correct fuze would be used with a particular missile.

It soon became obvious that a fuze, working on the barometric principle, would have to be placed in the missile in such a position that the pressure around it would be independent of the speed. From wind tunnel tests, carried out at the Royal Aircraft Establishment, it was found that the most suitable position was in the tail, and the No. 860 nose fuze was modified by removing the arming vane and incorporating in its place a 'T' bar which engaged the arming fork on the standard tail unit. This modified fuze became known as the No. 867.

The operating height of the fuzes, set at the manufacturers, was not adjustable in the service and since the height of functioning was dependent upon the prevailing barometric pressure and the height of the target, it was decided to indicate the static height of functioning by the addition of a letter suffix to the Mark number. The letters of the alphabet from A to J were chosen to represent static heights of 1,000 feet to 10,000 feet. Service personnel noted the forecast barometric pressure at the target, together with the height of target above sea level, and selected the appropriate A.B.C., etc.[1]

Both barometric fuzes in use at that time had the disadvantage that, if released below the height setting of the fuze, they would fire as soon as the arming vane had unscrewed, and this made them suitable for use only in missiles which would not damage the aircraft should premature functioning occur. The possibility of inserting a fixed delay in the magazine, thus making the fuze suitable for release at high or low altitudes, was discussed and resulted in producing a magazine, incorporating a one second delay, later increased to two seconds, to give the necessary safety factors.[2] The magazine incorporating this delay was slightly larger than the one fitted to the No. 867 fuze, and contracts for the new fuze, known as the No. 885, were placed in February 1944.

A fuze which could be set by the service, according to the circumstances prevailing, had always been a requirement and the possibility of providing such a version of the barometric fuze was investigated. It was suggested that the fuze should be fitted with three setting screws instead of one, giving three alternative settings, and that the two setting screws not required, should be removed by the service immediately prior to fuzing.

In order to increase the safety of the fuzes, a geared mechanism for release of the safety pin was incorporated, a friction type safety wire in the tail fuze, which having successfully passed trials at the A. & A.E.E. was introduced into the service, to replace the No. 867 Mark I and No. 885 Mark I in April 1945 as the No. 886 Mark 1.[3]

[1] M.A.P. File S.B. 32016/3.
[2] M.A.P. File S.B. 50626.
[3] M.A.P. File S.B. 33543.

PART III

BOMBING INSTRUMENTS AND EQUIPMENT

INTRODUCTION

The need for some means of assisting the pilot or bomb aimer to position his aircraft at a point in space which would ensure that a bomb when released, would fall on, or in close proximity to a pre-selected target, became apparent during the First World War, and initiated the development of sighting devices for the aiming of bombs.

It is proposed in this part to deal with those bomb sights which operate by direct visual means, and in this respect it is probably no exaggeration to state that British visual bomb sight design and development has generally been ahead of other nations. The term visual is used in the sense that unless the actual target, or some reference point in relation to the target, can be seen and identified by the crew of the bombing aircraft with the naked eye, that target cannot be successfully attacked with this type of sight. Efforts to overcome the limitation imposed by unsuitable weather conditions, by means of the application of radar, reached a high state of perfection during the Second World War, nevertheless high altitude visual bombing was still superior in accuracy to any other form at the time of the surrender.

The final accuracy of visual bombing was achieved by the use of three main types of sights :—

(*a*) The Mark XIVA—Stabilised Vector.

(*b*) The Stabilised Automatic—Tachometric.

(*c*) The Low Level Bomb Sight Mark III—Angular Velocity.

The last named was unique in that a new approach to bomb sighting problems—that of angular velocity which was much less critical to height errors than other orthodox sighting systems. As far as is known, no other efficient low level sight, devised paiticularly for attacking submarines, has been designed by any other nation.

The history of bomb carriers and associated equipment has also been included in this part of Volume I. The means of securing bombs and similar equipment to aircraft, and the means of releasing them, simply and instantaneously, had been hastily devised to meet the growing requirements of the First World War. The earliest carriers were heavy and clumsy, but by the end of that war the carriers in general use were, for their time, reasonably light, efficient and reliable. There were three main types at that time. The first was a somewhat heavy and clumsy design, consisting of a channel section of steel with downward adjustable extensions at the nose and tail to hold the bombs steady. The release hook was secured inside the channel member and outriggers were provided to secure the carrier to strong points in the aircraft wing. The second type was a lightened form of tubular steel, originally of Naval design, and the third was a light series pattern which consisted of a framework and four release hooks. The first two types were employed for the carriage of larger bombs—65 lb. to 550 lb., and were made in two sizes ; one for bombs up to 250 lb., and a stouter model for heavier bombs. The light series carrier was designed for bombs up to 40 lb. in weight.

From the end of the First World War until the outbreak of the Second, bomb development proceeded, as regards size and weight, at a slow pace, and then, as the possibility of war became a certainty, with ever increasing momentum to the ' bigger and better ' bombs of the latter end of the Second World War.

In the former war, bombs were rarely of such a size and weight, or the aircraft capable of carrying a load, such as to necessitate more than two men for the task of transporting them from the bomb dump and loading them on to the aircraft. The increased weight policy, even to the maximum of 500 lb. decided in 1922, indicated not only the inadequacy of the man handling method, but also increasing the danger of such procedure, and some suitable means of rapid and convenient conveyance, together with some method of hoisting the bombs into position into the aircraft had to be decided.

CHAPTER 19

BOMBSIGHTS

Early bombsights

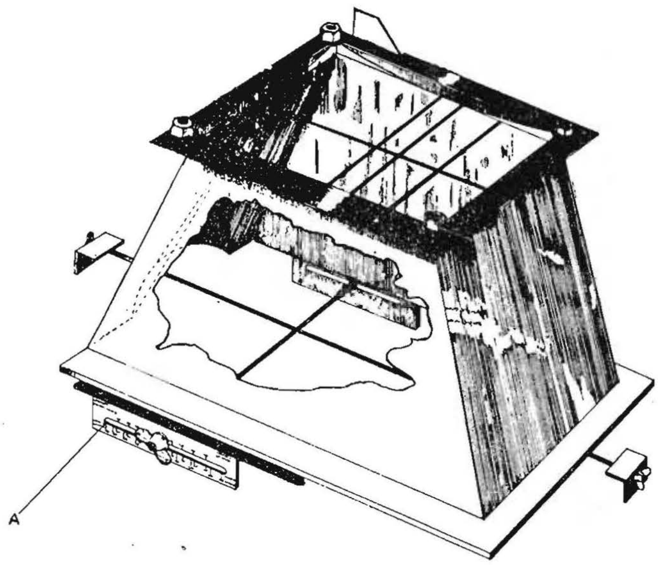
Incorporated in the design of the early bombsights of the High Altitude Drift series, was a means of measuring the velocity of the wind prevalent at the time when bombing was required, and in order to make this calculation, it was necessary to measure the 'drift' of the aircraft over the ground; for this reason these sights were known as 'Drift Sights.' They consisted of a metal framework on which height and ground speed (a combination of air speed and wind speed) could be set; their form was that of a triangle similar to one which would be described by a vertical line dropped from the aircraft to the earth's surface, a horizontal line, from the point of intersection of this vertical line with the ground, to the target, and a sighting line from the operator's eye to the target. Allowance for wind effect was made by restricting bombing to up or down wind attack and converting the 'Indicated Air Speed' to 'Ground Speed' by subtracting or adding the wind speed. Even on these early sights provision was made for independent levelling of the sight, and attempts to stabilise it, and therefore to make it independent of small oscillations of the aircraft, were made in the High Altitude Drift Sight Mark III (Stabilised).

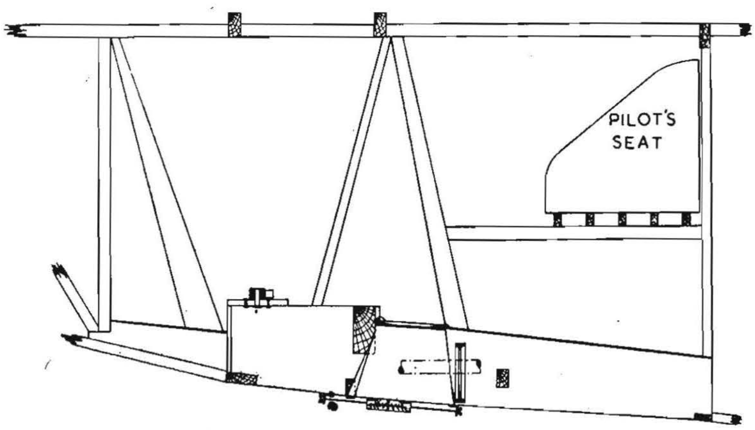
The High Altitude Drift Sight Mark 1A (H.A.D. Sight) was the first sight to be successfully installed and used in bombing aircraft. With this sight it was possible to bomb from altitudes of between 1,000 and 18,000 feet at air speeds varying from 60 to 130 miles per hour and in winds of up to 50 miles per hour. Due to the fact that a bomb, when dropped from a moving platform, 'lags' behind the actual aircraft, variable adjustment for this 'trail', dependent on the ballistics of the types of bombs then used, became necessary and was incorporated. It would probably be more accurate to describe this type of sight as a 'Vector' sight, in that the three vector[1] quantities—air speed, wind speed, and vertical speed of the bomb (interpreted in terms of height and adjusted for the bomb trail angle), were set on the bomb sight on the assumption that all of these quantities remained constant from release to strike of the bomb. Having established these three 'Vectors', a triangle was set up in the aircraft which was similar to the main 'imaginery' triangle described above, and it was the task of the bomb aimer to arrange for the positioning of his aircraft so that the pre-determined sighting line of the bomb point of impact intercepted the target at the moment of release.

It is convenient at this point to differentiate between the two major divisions in types of bombsight. The characteristic feature of the first type, or vector bombsight, is that the height, air speed, bomb ballistic data and wind speed and direction are supplied to the calculating system of the sight. The bomb aimer is presented with a drift line representing the track of the aircraft (or of the trail point) calculated from these data, and with a release point sight which comes on to the target at the instant of release.

[1] Vector—a quantity having magnitude and direction, being capable of graphical representation by a straight line.

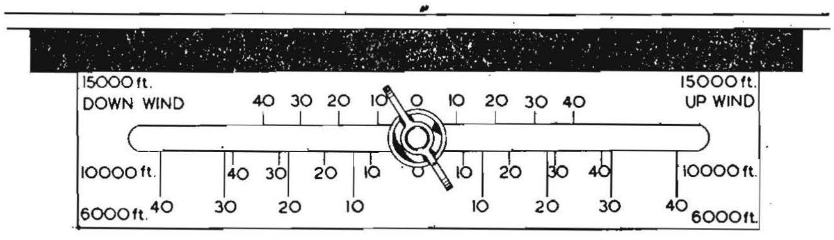
NEGATIVE LENS BOMBSIGHT





SIGHT FIXED IN D. H. 4., R.A.F., B.H.P., FUSELAGE

ENLARGEMENT OF 'A'



The second type—the Tachometric Bombsight—by observation of the movements of the target relative to azimuth and vertical datums in the aircraft, determines the ground speed and drift angle, and enables the aircraft to be manœuvred onto an interception course. This information, together with the height and bomb ballistic data which is supplied to the computing mechanism, is used to compute the correct instant at which to release the bomb.

To sum up: in vector methods of sighting, ground speed and drift angle are computed from the values assumed for the air and wind velocities and, in Tachometric methods, ground speed and drift are obtained by direct measurements of apparent target movement.

To return to the early history of sights: three other elementary vector sights, in use during the latter years of the First World War, need only brief mention :—(*a*) *The Negative Lens* sight which consisted of a rectangular concave lens fixed to the floor of the aircraft and arranged to give the pilot a reduced picture of the ground immediately below and ahead. Adjustable longitudinal and transverse wires, which served as sights and provided a means of estimating drift, enabled a correct up or down wind course to be steered; (*b*) The Central Flying School *Trombone* sight with which ground speed was determined by a timing method using a stop-watch and auxiliary target (it thus, to some extent, used a minor Tachometric principle); (*c*) The *Equal Distant* sight which employed a rather more complicated timing method using a reversible stop-watch; thus accurate timing of apparent target movement could be made, and the correct bomb release point measured automatically.

All these early sights had one common limitation; bombing was restricted to flight either up or down wind, but in 1916, the introduction of the Wimperis Course-Setting bombsight, brought the first great advance in the science of bomb sighting.

Bombsight development between 1916 and 1946 followed generally four main avenues :—

A. The unstabilised vector sight, of which the most important representative was the course-setting sight Marks I to X.

B. The stabilised vector sight (Marks XI, XII, XIV, XV, XVI and XVII).

C. Tachometric sights: principally the automatic bombsights Marks I and II, and the stabilised automatic sights Marks I and II.

D. Sights designed for special purposes, such as low altitude bombing, torpedo attack and attack of aircraft in flight.

A. The course-setting bombsight (C.S.B.S.)

The first really efficient bombsight was that designed by Mr. H. E. Wimperis, then the head of Air Ministry Laboratories, for attack on submarines.

Briefly this famous course-setting sight, which by 1917 had begun to supersede all others, and which for twenty-two years was to be the standard bombsight of the Royal Air Force (though with considerable structural and material modification), was virtually a mechanical vector triangle, whose three elements, air speed, wind speed and direction, and resulting ground speed could be measured. The first two were calculated and set on the bombsight by the bomb aimer, and the third was the resultant of their combination. The height bar, which carried a movable open back sight, was calibrated in aircraft height and was angularly adjusted (tilted) to allow for bomb ballistics.

Indication of the calculated point of bomb impact on the ground was continuously given by sighting through a back sight attached to the 'height bar', and a fore sight attached to the junction of wind speed and ground speed bars. Unfortunately two major difficulties were inherent in the design; in the first place the sight had to be level during 'run up' and release, and, although small spirit levels were provided, the smallest oscillation of the aircraft showed a much magnified error in indicated point of impact on the ground; and secondly, corrections in course, given by the bomb aimer to the pilot in order to 'track' the aircraft directly over the target, involved an adjustment of all three sides of the vector triangle which, although semi-automatic through a system of gears, did involve continual re-orientation of the sight with the magnetic compass; or, in the well-known phrase of the bomb aimer—Keeping 'Red on Red'.

Due to the excessive displacement of the indicated point of impact during the normal turn, it was necessary for all alterations of course, during the bombing run, to be made with 'flat' turns, but by careful team work between bomb aimer and pilot, bombing accuracy, at any rate under peace-time conditions, could be high, and by 1930 had reached a standard which has not since been generally exceeded.[1] In addition to its sighting accuracy, the C.S.B.S. provided a reasonably accurate method of measuring wind speed and direction and could, therefore, also be used as a navigational instrument.

Although between 1917 and 1939 fourteen variants of the original sight were produced, the only major changes in design occurred in 1937 with the introduction of the Mark IX sight. This, apart from an increase in the maximum air speed allowance to 240 m.p.h., differed essentially from all its predecessors in that a modification to allow for automatic vector orientation by means of a 'Distant Reading Compass' (D.R.C.) was subsequently proposed. It was, however, only produced in this 'complete' form in limited numbers and never used in operational service.

At the beginning of the Second World War, the course-setting sight was still the standard instrument in general use in Bomber Command and, of the five operational Groups then in existence, four were equipped with C.S.B.S. Mark IX, (Battles, Blenheims, Wellingtons and Whitleys), and the fifth, equipped with Hampden aircraft, had the automatic sight, development of which had commenced in 1933.

Brief history of C.S.B.S.

The original Mark I C.S.B.S., designed for the low level attack of submarines, allowed for bombing between 200 and 2,500 feet, at air speeds from 55 to 100 knots, and in winds of 0–50 knots; it was followed, in the years 1919 to 1930 (the 'lean' years of armament development), by a Mark II version adapted for high altitude bombing. Apart from two special 'low speed' designs, Marks III and IV, introduced in 1920 for use in airships, the Mark II persisted, with various modifications until 1930. These modifications were necessary in order to keep pace with the ever increasing performance of new aircraft and the improved ballistics of bombs; they were, however, not of a sufficiently major nature to alter the mark number, and instead the letters 'A' to 'K' were added to their Service nomenclature. Only two of these are

[1] From 10,000 feet at an air speed of 80 to 100 m.p.h., 50 per cent. of errors were 50 yards or less.

worthy of special note—the IIH produced in aluminium instead of brass and thereby reducing the original weight by almost one half, and IIK which had levels and vector bar graduations illuminated for night use.

The Mark VI, in an attempt to reduce total weight, was produced in aluminium, but proved so fragile that within a year was replaced by Mark VII which, apart from reverting to the original solid brass structure and remaining a general purpose bombsight, was equipped in addition with a fourth vector mechanism, designed for use against ships. On this enemy speed could be set and automatically allowed for in the mechanical vector triangle previously mentioned. Three types, ' A,' ' B ' and ' C, ' were produced, the latter two being specially calibrated in knots for Fleet Air Arm and Coastal R.A.F. Squadron use, but apart from this they only differed if the maximum and minimum limits of height and speed. The Mark VII was in many ways a great improvement on its predecessors, and all three versions combined most of the modifications evolved by the Air Ministry Laboratory up to 1930. Principal among these were :—

(*a*) An improved alcohol-filled compass.

(*b*) A target vector (0 to 40 knots).

(*c*) Increased wind speed allowance up to 60 knots.

(*d*) Interchangeable height scales representing more accurately ballistics of individual bombs.

(*e*) More exact variation of trail angle with air speed setting.[1]

(*f*) Use of better materials and enclosure of the mechanism to minimise possible troubles from dust and erosion.

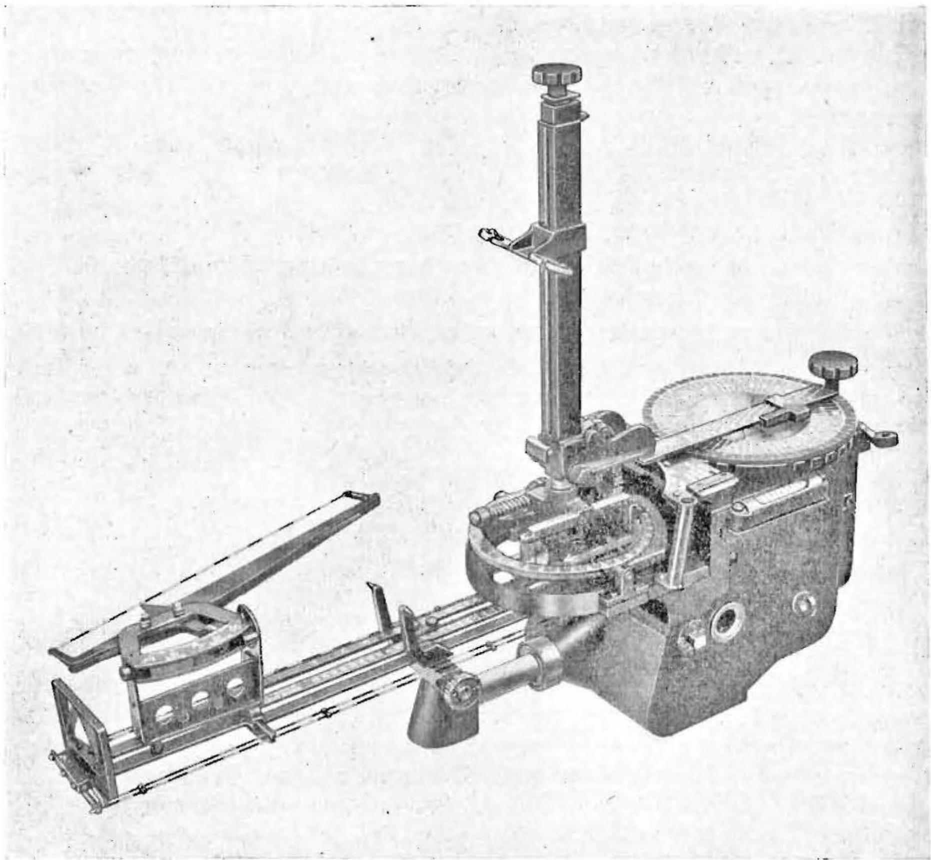
The Course Setting Bombsight was by now a highly efficient instrument, and with it, in practical hands, astonishingly accurate results could be obtained. It has to be realised, of course, that the majority of these were under ' Practice Camp ' conditions, and were thus often artificial. Many attempts, such as the insistence that the bombing aircraft should be engaged on other types of flying exercise for at least an hour before actual bombing commenced, so that the crew might be to some extent tired, were made in an effort to introduce some kind of ' active service ' reality, but the fact that the C.S.B.S. demanded a period of straight and level flying during the ' run-up,' and this, combined with the keen competition between bombing squadrons, tended to preserve the air of unreality. A comparison of errors is, however, worthy of mention : in 1940 average bombing errors of 50 yards from 10,000 feet were a normal achievement, whilst over Germany in 1943 errors of 200 to 300 yards were the common order.

The Air Ministry Laboratory was finally disbanded in 1932 after it had produced its last varient of the C.S.B.S., the Mark VIII, and thereafter new sight design was largely in the hands of the Instrument Department of the Royal Aircraft Establishment at Farnborough (R.A.E.).

The first great advances in vector bombsight design occurred in 1937 with the advent of the Mark IX C.S.B.S., designed by Mr. W. H. Coulthard of R.A.E. This sight, apart from increases in speed and height units, made necessary by the development of faster aircraft, was capable of embodying an improvement of major importance—automatic orientation of the sight by

[1] In Mark VII and subsequent sights, the setting of ' trail-angle ' in degrees was replaced by a bomb ' terminal velocity ' setting in feet per second.

means of an electrically controlled 'Distant Reading Compass.'[1] Although this modification went into production, it was never used with the bombsight in practice, and despite the absence of any traceable reason, it is fairly safe to assume that the tactical limitations which all the marks of C.S.B.S. presented, was one of the main contributory factors. As with Mark VII, three variations of Mark IX were manufactured differing, as did the former, in miles per hour and knots calibrations. The trail angle setting had by this time been made easier by interpretation in terms of 'terminal velocity,' and the T.V. of each type of bomb being a known constant and permanently marked on the relevant height scale, led to increased rapidity of the 'setting' operation, and ultimately greater bombing accuracy.



COURSE SETTING BOMBSIGHT, MARK IXC

Tactical limitations of the C.S.B.S. have already been mentioned, but it is essential to realise what these limitations were in order to appreciate why this bombing instrument was far from ideal during active service. Briefly, by

[1] The 'Distant Reading Compass' was evolved to overcome the turning-errors inherent in the normal Magnetic Compass. The 'D.R.C.' has an electro-magnetic detector unit which can be situated in a part of the aircraft which is comparatively free from the deviation effects of the aircraft's magnetic field. The aircraft heading is transmitted electrically to repeater dials in the pilot's, navigator's and bomb-aimer's stations, and in this case operated the mechanism for re-orientating the bombsight.

virtue of its design, the bombsight could not accurately predict the point of impact of a bomb unless maintained in a level position during the run up to the target. This called for extremely accurate flying and intense concentration on the part of the pilot. The period from 'turning on' to 'bombs gone,' even on a perfectly judged run, was considerable, and during that period the aircraft became an easy target to the defenders.

In the majority of cases, the perfect run was more a matter of luck than judgment, and frequent alterations of course were necessary in order to 'track' the aircraft over the target; but the sighting line was fixed relative to the aircraft's axes, and since the desirable 'flat' turn became increasingly more difficult with the advent of the more aerodynamically efficient aircraft which started to appear in 1937, allowance for a 'banked' turn became imperative.

A banked turn meant that the relation between the fixed sighting line and the target would be lost during the time taken to turn, and in consequence the amount of turn necessary had to be assessed before the turn was commenced. Add to this the training required for the bomb aimer to become competent to judge the turn accurately on a normal magnetic compass, and remembering that the bombsight required manual re-orientation with the compass after the needle had settled, and it will be realised that length of 'run-up' to the target had to be considerably increased so that the aircraft could be accurately settled on its course early on 'target approach,' and the fatal last minute corrections avoided. One final point is worthy of mention: familiar to all users of the C.S.B.S. was the almost inexplicable habit of the target having conveniently 'drifted' down the drift wires, to 'wander-off' at the last minute when corrections were impossible and thereby ensuring a large ground error. This was invariably due to incorrect drift being set on the sight, and not becoming apparent until too late in the run.

One attempt to assist the bomb aimer in his unenviable task was the 'azimuth bracket.' The sight was mounted on this bracket, which, as its name implies, could be rotated in azimuth, *i.e.*, rotated about the vertical axis. Thus when a turn was required, the whole sight could be rotated, the amount of turn required electrically recorded in degrees on the pilot's instrument panels, and within a very small error, the sight manually adjusted to a position where it would be re-orientated when the compass needle had finally settled. The device soon lost popularity in the early days of the Second World War; it could not be used unless the target could be easily and rapidly identified, and this factor, except in isolated occasions, prohibited its use at night. As the war progressed it became increasingly difficult to identify the target even under ideal conditions, and the azimuth bracket rapidly fell into disuse.

The course-setting bombsight, Mark X

One final effort was made to prolong the life of the rapidly dying course-setting series—the design of an entirely new sight—the Mark X. This sight embodied automatic vector orientation by means of a distant-reading compass, but, like its predecessor, the 'complete' Mark IX, did not come into service. Several improvements were incorporated in its design to ease the task of the bomb aimer, but the n ed for providing extended scales to accommodate the ever increasing ranges of height and speed of the modern bomber, and the vast range of height scales for bombs of varying ballistical qualities, was converting the C.S.B.S. into an instrument so unwieldy as to be operationally impracticable.

A computor, separate from the sight, capable of covering the widening ranges of height, airspeed, and terminal velocity was provided, and a further much needed simplification was the use of ' indicated ' instead of ' true ' settings on the sight. On all previous marks of vector sight it had been necessary, by means of a hand computor, to convert the indicated (instrument) readings to the actual (true) readings for which the sight was calibrated.

The days of the Course Setting Bombsight were, however, already numbered. It gave twenty-four years of useful service, and was in fact the bombsight in general use at the outbreak of th War, being the standard bombing instrument for four out of the five Operational Groups of Bomber Command at that time.

B. Stabilised vector sight

In the previous description of the C.S.B.S., considerable stress has been laid on the tactical limitation which these types of sight entailed, and this, coupled with the complications introduced into the sight since Wimperis's first simple model in 1917, and the ever increasing ranges of speed and height, imposed more and more tasks on the bomb aimer and heralded the sight's eventual abandonment. The factor, however, which under war-time conditions seriously limited the successful use of the Course Setting Sight was the absence of stabilisation. To understand this fully requires a fairly sound knowledge of the mathematical theories underlying the principles of bombsighting.[1]

The axes of rotation

An aircraft has three axes of rotation—roll, pitch and yaw (azimuth)—and it is about these axes, or within these planes of motion, that the aircraft, and in consequence the bombsight, may be said to move. As will be realised later, and from the view of successful bomb-aiming, the rolling plane is the most important, closely followed by pitch.

The Rolling Plane.—When an aircraft turns about the fore and aft axis, as it must do during a ' banked ' turn, the unstabilised sight will cease to indicate the line along which the bomb will strike, and it is not until the aircraft has completed the turn, and is once more straight and level, that the correctness of the amount of turn completed can be judged. The azimuth bracket eased the problem, but, due to its limited application, did not provide the final answer.

The Pitching Plane.—When an aircraft turns about its pitching axis, as apparent during even the slightest movement to climb or dive, it is necessary, in order to forecast the position in which the bomb will strike, to move the sight relative to the aircraft by an amount equal and opposite to the angle through which the aircraft pitches, and at the same time make allowance for the consequent change in vertical speed or time of fall of the bomb.

The Yawing (Azimuth) Plane.—When an aircraft turns about its yawing axis and ' crabs ' relative to the surrounding air, the air speed and vertical speed vectors remain unchanged, but wind speed and enemy speed vectors need reorientating without which, an entirely false position of strike is forecast.

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[1] For such an exposition consult ' The Art of Bombsighting'—a scientific and historical monograph on aircraft bomb and torpedo aiming by W. H. Coulthard, B.Sc., published by the Ministry of Supply.

The answer to these problems in vector sight development was stabilisation and this was accordingly attempted on those sights produced after the outbreak of the second world war—the Marks XI, XII, XIII and XIV. Brief notes on these sights are given below in an attempt to enable the reader to form a mental picture unobstructed by technicalities.

The Mark XI Sight.—This, the first sight to use any form of stabilisation, was an attempt to overcome the tactical freedom bugbear of the C.S.B.S. series and for this reason, was only stabilised for the rolling plane. An existing gyroscope, that used in the 'Sperry Artificial Horizon' was utilised with a single drift wire and an open back sight mounted on the outer gimbal ring. Possibly the simplest method of outlining the working of the sight is to give the procedure required of the bomb aimer :—

(*a*) Level the sight.

(*b*) Set wind speed and direction, estimated course of attack, and agreed indicated air speed during attack, on Course and Speed Calculator (C.S.C.).

(*c*) Set indicated ground speed and bombing height on circular computor and read off the computed bombing angle.

(*d*) Set drift and bombing angles on sight.

(*e*) Give pilot verbal instructions to bring sighting line onto the target.

Since the sighting line maintains a fixed position in space unaffected by roll it is not necessary for the target to track continuously down the drift wire and, provided the estimated settings agree with the actual at the instant of bomb release, the target may be approached in a series of correctly banked turns.

The Mark XI sight certainly introduced limited stabilisation but at the expense of additional complications and the use of a hand manipulated computor.[1]

Generally the sight showed no marked advance on its predecessors. The increase in tactical freedom, so desirable, was so small that only a very limited number were produced and the sight soon went out of use.

The Mark XII Sight.—This sight showed a distinct advance in bombsighting technique : it consisted of two units—the sighting head and the computor unit. The former resembled the previous sight except that the setting knobs for bombing and drift angles, were replaced by flexible drives which transmitted the required settings from the computor unit which was situated in another part of the aircraft, and the drift wires and open sight were replaced by a 'collimator' (tubular sight), which projected the image of a graticule on to a reflector plate coupled by a linkage to the outer gimbal ring of the gyroscope, and gave greater eye freedom to the bomb aimer.

The computor unit was virtually a second instrument panel equipped with an airspeed indicator, an altimeter and an artificial horizon adapted, by means of a pointer recording over an angular scale, to indicate angles of pitch assumed by the aircraft. Adjacent to each instrument was a handle controlling a needle indicator and coupled to a mechanism capable of computing the bombing angle and transmitting the result, by means of flexible drives, to the sighting unit. A means of offsetting the instrument readings to allow for target height and

[1] *See* 'The Art of Bombsighting' by W. H. Coulthard, B.Sc.

the range component of the wind speed was provided, but although from the bomb aimer's point of view the sight was a great improvement on all which had preceded it, constant manipulation of the handles was necessary in order to keep the pointers coincident with the three instrument needles, this called for an additional member of the aircraft's crew known as the ' bomb-aimer's mate ' and at the same time condemned it as a practical sight.

The Mark XIII was never introduced into the service since it only showed constructional improvements of the Mark XII whilst maintaining its operational undesirability—the ' bomb-aimer's mate '.

The Mark XIV Sight.—This famous sight, which owed much to the inspiration of Professor Blackett and his separate units principle, was the work of Dr. H. J. J. Braddick of R.A.E. Like the Mark XII it consisted of two units—Sighting Head and Computor, but with the essential difference that the latter was made automatic and in consequence a human bomb aimer's mate became unnecessary. Control knobs were provided for setting wind speed and direction, target height, sea level pressure and terminal velocity, and the ' computor box ' did the rest, height and air speed were measured and automatically computed, and from this, with the course fed in by the Distant Reading Compass (D.R.C.), continuous computations of the sighting and drift angles were fed into the sighting unit, and maintained sight orientation.[1]

Eight variations of the Mark XIV sight were designed, Mark XIV, XIVA and B, T1, T1A and B, XV and XVII. The ' A ' sights were fitted with a more accurate sighting angle mechanism and covered a greater range of height. Instrument position error and attitude correction cams were interchangeable, enabling the same computor unit to be used in any type of aircraft. The ' B ' sights were similar to the ' A ', except for gyroscopes which were driven electrically.

The Mark XV was designed for low level operations against submarines and, because small errors in height settings at very low altitude produced large bombing errors, accuracy in setting was obtained by linking the servo height motor to a radio altimeter. The Mark XVII was a version of the Mark XV specially designed for use in Naval Mosquito aircraft. The air speed range was extended to 400 miles per hour, and because there was no bomb-aimer's position in this type of aircraft, an unstabilised sighting head was used. Neither the Mark XV nor the Mark XVII was, however, brought into service use.

The ' T ' series of sight were identical to the original Mark XIV and the only purpose in the difference in title was as a means of ready reference to those manufactured in the U.S.A.

C. Tachometric bombsights

The principle of the tachometric system of bomb aiming has previously been mentioned as that of direct measurement of apparent target movement The reason for its adoption was to eliminate the very difficult task of finding an accurate windspeed and direction and thereby increase bombing accuracy. Before discussing the sights which employ the tachometric principle, it is necessary for the purpose of clarity to enlarge a little on this principle and thus give the reader some knowledge of how it has been employed in bombsight design and development.

[1] The highly complicated mechanism for computation prohibits a detailed description in a narrative of this nature, and the reader is once again referred to ' The Art of Bombsighting' by W. H. Coulthard.

The previous writings in this chapter on the vector sights have implied the solution of the range problem, as being the setting up in the aircraft of a line of sight which is inclined at a fixed angle to the vertical, and predicts the point of impact of a bomb if released at the instant of observation along this sighting line. The tachometric principle tackles this problem by allowing for the constant alteration in the tangent of the angle between the vertical and the line joining the target to the operator's eye as the target is approached.

It will be realised that as the target is neared, the angle between the sighting line and the vertical[1] decreases, and at the same time the apparent movement of the target (its angular velocity), increases ; if then a line of sight which instead of having a fixed inclination, is maintained on the target during the approach, it will vary its angular position as the sighting angle varies, and at a speed proportional to the target's angular velocity. Knowing the air speed, altitude, and the ' trail distance ' of the bomb being dropped, it is obviously not an impossibility to drive the line of sight mechanism, so that at the correct dropping angle the bomb itself is automatically released. It was on this basis that the automatic bomb sights were developed.

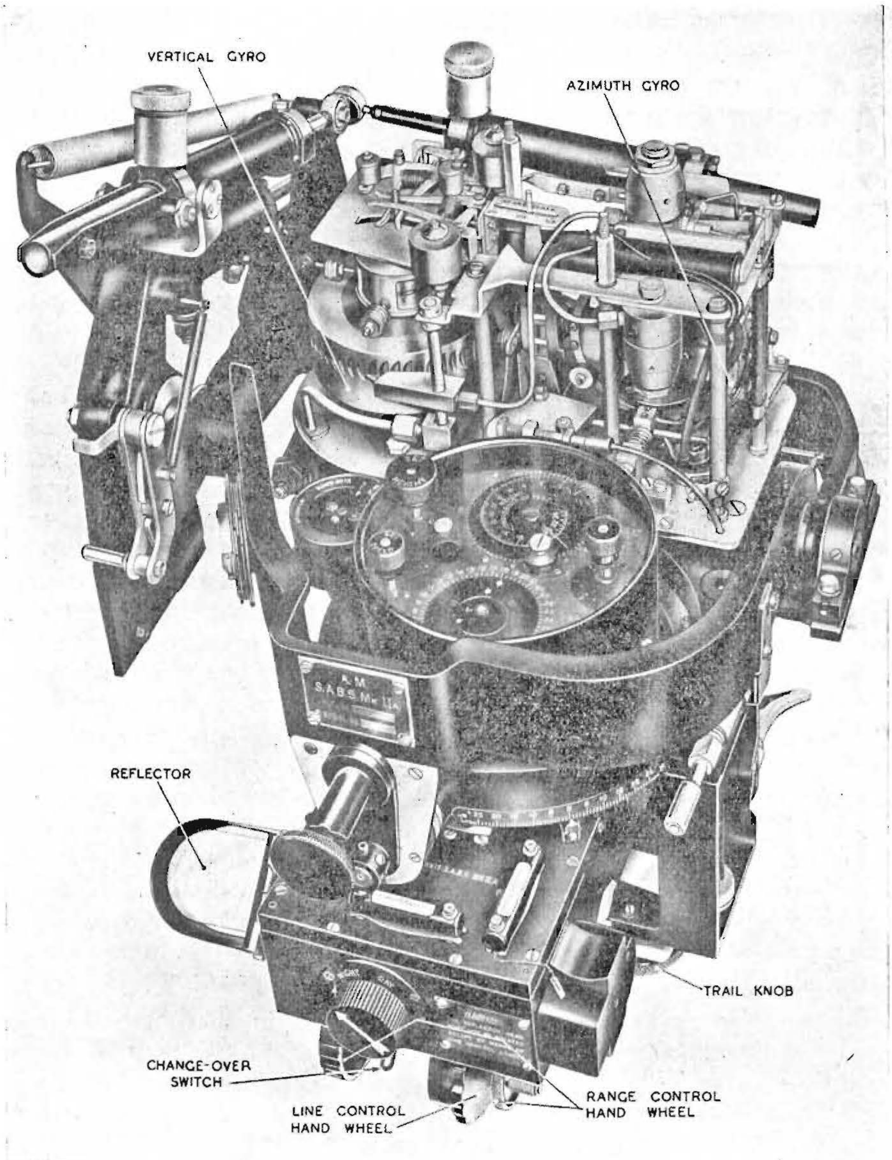
Development actually was commenced at the Air Ministry Laboratory concurrent with the vector course setting sight. Two such sights were designed which, although they did not reach the service, provided the foundations upon which all subsequent sights were built. The first, provided with open sights, was automatic in range only, as described above, and required manual orientation in azimuth by direct observation of the target. The second had a telescopic sighting tube with automatic azimuth adjustment which, by means of a direct coupling to the automatic pilot, steered the aircraft on a curve of pursuit to the correct point of bomb release. Both of these early sights, and the Type ' B ' Marks I and II which followed, suffered from the same weakness as the early vector sights—they were unstabilised and were designed on the assumption that the aircraft was capable of making flat turns.

It was soon realised that the only solution was to stabilise the sight and the first effort in this direction was made in the summer of 1939. The sight (the Automatic Bombsight Mark II), was mounted on two brackets capable of sliding on vertical pillars with the position of the brackets controlled by Bowden cables led in from a specially mounted Mark IV Automatic Control Unit. There were so many mechanical difficulties however with this arrangement, that the scheme was abandoned in December 1939, and work commenced on the prototype stabilised automatic sight which eventually developed into the Marks II and IIA sights used during the Second World War.

This prototype sight was a self-contained unit in that both bombsight and stabilising unit were mounted on a common platform within a gimbal system, the pivots of the outer gimbal ring being carried on brackets secured to the aircraft. The stabilising unit consisted in the main of two air-driven gyroscopes, one in azimuth and one in the vertical plane, with a pendulum system for vertical erection, and a pneumatic servo system to provide the power for stabilising the main bombsight platform. The unit was so arranged that a combination of pendulum and gyroscope for roll erection, and the simple pendulum for pitch erection, enabled true vertical to be defined during a banked turn.

[1] The sighting angle.

This prototype sight was sent to the Aircraft and Armament Experimental Establishment (A. & A.E.E.) at Martlesham for exhaustive tests which, after the incorporation of several modifications, were completely successful. A production order followed and delivery commenced in August 1940. Unfortunately the initial flight tests revealed several defects in manufacture, and it was



STABILISED AUTOMATIC BOMBSIGHT, MARK IIA

realised that before sighting accuracy could be hoped for, a much more rigid specification for various manufacturing processes was required. One of the principal sources of trouble was a relay valve system by operation of which, diaphragms at low pressure controlled the movements of the servo motors. To eliminate the fault of this system, designed by R.A.E., involved practically a complete redesign, and it became evident that production of a new and more severe specification would be very difficult.

By March 1941 however, after extensive investigations into other methods of stabilisation by R.A.E., the Admiralty, and several private firms, three new servo systems were evolved,—' Electroflo ', ' Desoutter ' and R.A.E. The ' Electroflo ' system dispensed with the previous valve system, and servomotors were operated directly by high pressure air jets controlled by blades in the gyroscopes. This design was unsuccessful for two reasons: the maximum response rate of the servomotors was unduly small, and the performance of the jets fell off at high altitudes. The Desoutter model also dispensed with relay valves and instead, used a leak-valve system with the valve pistons coupled direct to the gyroscopes. The R.A.E. model was a version of the original prototype with an improved relay valve system.

Comparative trials of the three new systems showed the Desoutter design to be the best, with Electroflo a good second, and accordingly ten of each type were produced for air trials. By April 1941 the trials had resulted in the choice of the Desoutter model, and the remainder of the year was spent in a further series of trials and modifications particularly to the roll pendulum and the vertical gyro precession gear. The commencement of the new year saw the start of work on the new redesigned sight—the Stabilised Automatic Mark II.

In the spring of 1942 the first issues of the new sight were made to the service, some to Hampden aircraft for training purposes, and the remainder to Lancasters of Bomber Command for trials under operational conditions. As a result, mainly of the latter, some minor modifications were found to be necessary and their embodiment produced the final Mark IIA Stabilised Automatic Bomb Sight (S.A.B.S.), which was used throughout the remainder of the war.

An operational comparison of Vector, Mark XIV, and Tachometric (S.A.B.S.) sights

A comparison of two such widely differing forms of bombsights in a narrative of this description can only be given from the viewpoint of the operational efficiency of purpose of the separate sights.

Firstly, the bugbear of the Course Setting Bombsight—tactical freedom. There was in fact very little difference in this respect between the two sights since in both it was desirable that the last twenty seconds before bomb release should be straight and level. Given this period there is no doubt that the S.A.B.S., and corresponding sights developed in the U.S.A.—the ' Sperry ' and ' Norden ', gave the more accurate results. If however the target was heavily defended, and manœuvre was necessary during the whole of the run-up, the accuracy of both sights fell away rapidly. The necessity for violent manœuvre in the final twenty seconds could however be minimised by high altitude attacks since for obvious reasons the higher the aircraft, the less was the time available for the enemy anti-aircraft gunners to predict, lay, and fire their guns to project a shell to detonate at the required altitude. On the other hand, provided that an aircraft equipped with a S.A.B.S. maintained a constant height and air-speed during the required twenty seconds, accurate bombing if not assured became highly probable. This unfortunately was not true with the stabilised vector for the following reasons :—the wind velocity set on any sight should be that over the target at the moment of release, but the wind set on the Mark XIV is normally that obtained by a series of navigational observations over a long period of flight, much of which was distant from the target. This might lead to an error in this most vital setting with a resultant bombing error ; as the tachometric sight estimated the wind by observation of the actual target, the possible error in estimation might be reduced by some 75 per cent. It was for this reason that, to the R.A.F., the Mark XIV was termed ' the area sight ' and the S.A.B.S. ' the precision sight '.

As regards bomb aimer training, although that required for the S.A.B.S. might be said to be more skilful, there was in fact little difference in the time before a bomb aimer might be regarded as fully trained. The period of training however, which elapsed before an actual bomb was dropped from the air, was greater in the case of the S.A.B.S., but once this stage was reached, practice was the only remaining requirement, whereas with the stabilised vector it was normal to allow active operation from the air quite early in the training period.

During the Second World War, the use of the automatic sight was very limited. The unstabilised version in use at the outbreak was completely ineffective and it was not until August 1943, when development of the stabilised version was completed, that a squadron was equipped with the S.A.B.S. and given training in its use. Comparable with the tonnage of bombs dropped by the remainder of Bomber Command equipped with the Mark XIV, that of the S.A.B.S., with its rigorous maintenance and use mainly for special types of raid, is insignificant. Although the Mark XIV was the best sight so far designed for general use, its results at the beginning can only be described as disappointing ; accuracy did of course improve towards the end of the war but only as a result of an emphasis on training, and meticulous attention to sight maintenance.

D. Sight for Special Purposes

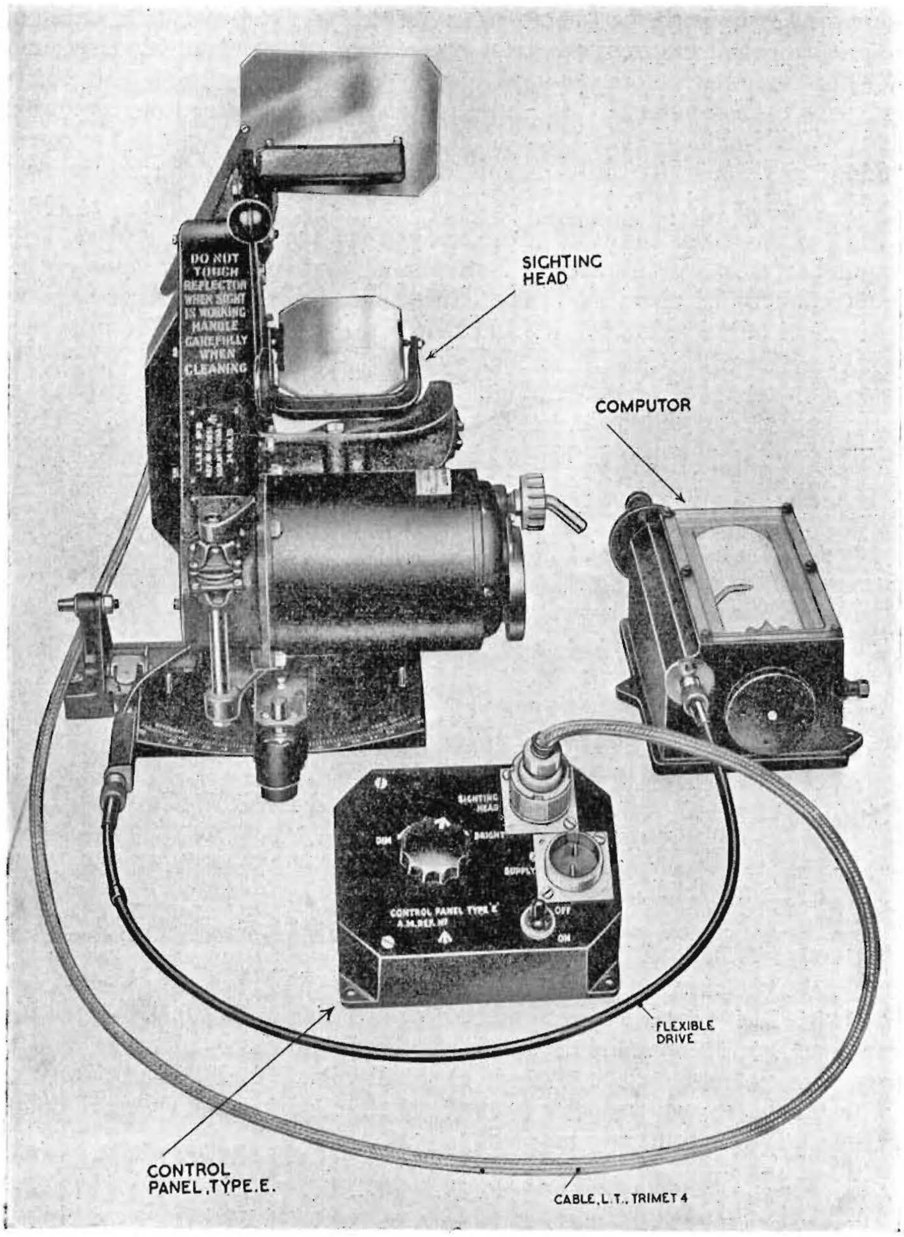
Low Level and Dive Bombing Sights

At the outbreak of the Second World War, no official Low Level or Dive Bombing Sights were in existence in the Royal Air Force. This implies no criticism of the Instrument Department of R.A.E. who were responsible for all bombsight design after 1930, but merely evolves on the generally held theory that, in the case of low level attacks, practised bombing crews could bomb accurately between heights of 30 to 100 feet without any sight at all, this being borne out largely by the small average errors of 20 to 30 yards by many bombing squadrons, and in the case of dive bombing, by the fact that this form was never officially recognised, and that in any case it required a specially designed aircraft which had never become a requirement.

Since at very low heights the events of a bombing run happen so quickly, there is little time for the passing of instructions from bomb aimer to pilot, and although ' low level attachments ' were produced for the Course Setting Sights from time to time, the majority of low level bombing attacks were made by the pilot. In 1939, however, development of low level sights did begin and the first to be introduced into the service took the form of a ' hand held ' bomb-aimer's sight—the L.L. Mark I.[1] This sight was really a modification of the Abney hand-held surveyor's level on which an angle can be set and maintained by keeping the spirit-level bubble central. Numbers of the Mark I were available in the early months of the war, but both sight and method were soon abandoned. When the pilot bore the responsibility of tracking directly over a

[1] Air Publication 1730A, Volume I, Chapter 7.

target, the bomb aimer divided his attention between holding his sight rigid and level, adjusting his sight settings to the correct true ground speed and true height, selecting and fuzing the bomb, and watching the target. The need



Low Level Bombsight, Mark III

for an efficient instrument for low height attacks on U-boats soon became apparent and the strongest representations for an efficient low level sight were made to the Air Ministry by the Commander-in-Chief, Coastal Command. The first significant result was the Mark II (O) (Observer's pattern),[1] which became available in small numbers in 1940, designed by Professor Blackett on the 'two man' principle.

The sight consisted of two units, sighting head and computor box. The computor box operator, or 'bomb aimer's mate,' was responsible for obtaining the essential elements from a hand-operated computor and setting them upon the sight computor before the attack, and for maintaining the height pointer reading on the computor box, the same as the altimeter reading from commencement of the bombing run till bomb release. From these settings the correct bombing angle automatically computed and fed into the sighting head by flexible drives.

The sighting head consisted of a free gun reflector sight, the Mark IIIA, mounted on an azimuth bracket. Both bracket and sight required some slight modification for incorporation as the sighting head the main difference being the replacement of the gunner's 'ring and head' by a graticule showing a drift line and a short cross line indication of the point of release. The bomb aimer was required to turn the sighting head by hand so that the drift line was on the target, and releasing the bomb at the correct moment.

The sight was rapidly followed by a modified version, the Mark II(O)A, differing only in the computor box charts provided for different types of aircraft, and an additional cross line on the graticule for harmonising purposes. The method of use was, however, precisely the same, and both had but limited success due, in the main, to the high degree of co-operation required between the pilot, who was once again responsible for tracking his aircraft over the target, the bomb aimer's mate, and the bomb aimer, and the difficulties which obtained with the very low altitude attacks which anti-submarine bombing demanded.

So far the development of the low level sight had followed that of the high level sight in that the release of the bomb was made when the angular position of the predetermined sighting line and the target were coincident. At low altitudes, however, the angle between the horizontal and the line joining the operator's eye to the target, even at short distance from the target, was extremely small, and increased in size very rapidly as the target was neared; also the slightest error in height estimation produced a large ground error and resulted in inaccurate bombing.

A bombsight operating on a different principle was obviously needed, and early in 1942 investigations were proceeding into two proposed sights, the first a low level version of the Mark XIV with a radio altimeter adaption, and the second on a new principle and known as the Angular Velocity Bombsight.[2] It is with this latter sight, which eventually became known as Low Level Bombsight Mark III, that it is now proposed to deal.

Low Level Bombsight, Mark III

In this sight the correct moment of release was established by measuring the angular velocity of the target, that is to say, the rate at which the angle between the vertical and a line joining the aircraft to the target changed. By this means, errors in height estimation could be ignored and, when combined with a radio altimeter, the sight achieved a hitherto unknown accuracy.

[1] Air Publication 1730A, Volume 1, Chapter 13.
[2] A.M. File C. 35637/1.

The Mark III sight was introduced for service trials in late 1942. The report on the trials contained the following recommendation :—

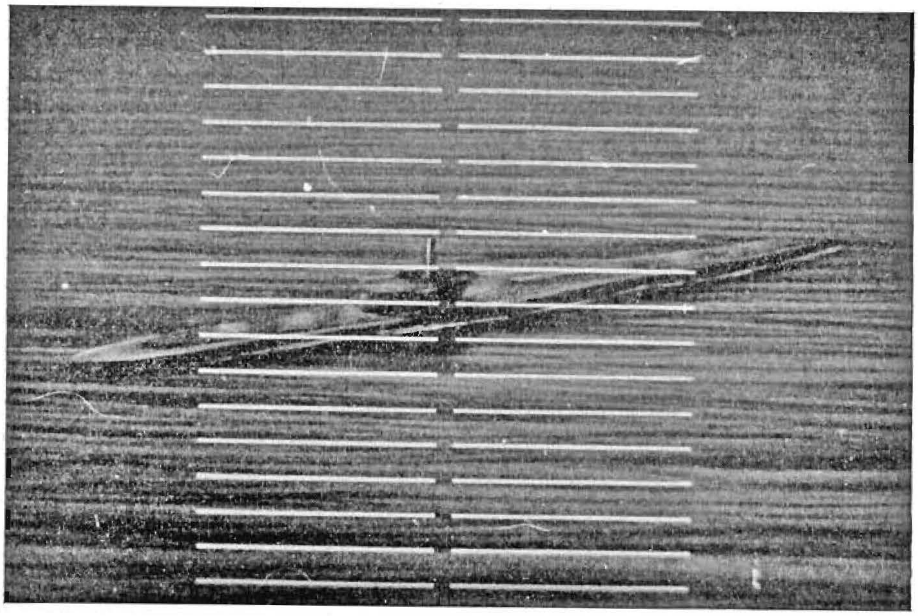
'For normal operational requirements it is considered that A.V.B.S. (Angular Velocity Bombsight) is by far the most efficient low level bombsight available for Coastal Command, and also low level daylight bombing on small targets, for the following reasons :—

(*a*) It is simple in use and sighting.

(*b*) No height setting is required for accurate stick bombing ; thus, only one adjustment, namely, approximate ground speed, is required on the computor box.

(*c*) Accurate bombing may be done in a climb or a dive, or following evasive action.

(*d*) Late sighting is no deterrent.'[1]



U-BOAT IN GRATICULE OF LOW LEVEL BOMBSIGHT, MARK III

On 22 December 1942 the sight was officially introduced into the service,[2] and at the end of the month A.C.A.S.(T) stated an immediate minimum requirement of a hundred of these sights to be known as L.L.B.S. Mark III.

The sight itself once again consisted of two units, computor box and sighting head, but this time gyro stabilised in pitch. The method of depicting the moment of release was novel and worthy of mention ; it was done by presenting a graticule which appeared to the bomb-aimer as an illuminated step ladder. This ladder moved down the graticule plate in accordance with the ground speed set on the computor box chart, thus when referred to a datum point on the terrain below the aircraft, was in fact a measure of the angular velocity. The

[1] A.M. File C. 35637/1.
[2] A.M. File H.S. 71811.

normal datum point was, of course, the target which 'moved' down the overtaking ladder, getting faster and faster as its range decreased until that vital moment when the speed of ladder and target were the same, and in reference to the moving ladder, the target was motionless. This was the correct moment at which to release the bomb.

Apart from a few minor modifications which became necessary on fitment to various types of aircraft, the Mark III soon became a standard item of bombing equipment for aircraft during the Second World War which employed this type of attack.

Dive Bombsight

As previously mentioned, there had been virtually no development of dive bombing aircraft for the Royal Air Force, and consequently the need for a special sight had never become a requirement. During the war, however, various American and German sights were tested, and some work on integrating accelerometers was commenced, but only experimental designs were completed.

The need for some form of sight for use in shallow dives (20 to 30 degrees) did become urgent with the introduction of rockets, but this need was met by a special method of usage of the pilot's gyro gunsight. With very little practice this gave extremely accurate results, and a similar method was in use for steep dive bombing training at Flying Training Schools.

The Scatter bombsight

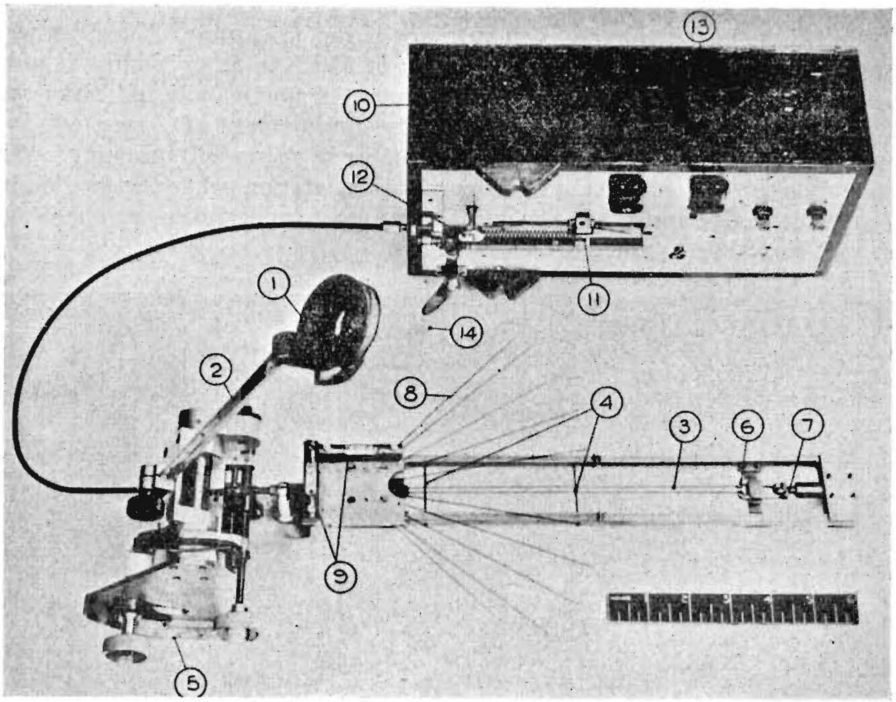
In 1936 and 1937 a scheme was afoot for attacks with bombs against enemy formations in the air. Initial flight tests, using rough sights, indicated that this method of attack might be effective from a position of some one to three thousand feet above the target formation. The sighting problem was by no means an easy one. The relative height of the target had to be obtained, which involved the incorporation of a rangefinder within the sight, and the relative speed, for which a 'timing bead' method was advocated, had also to be established.

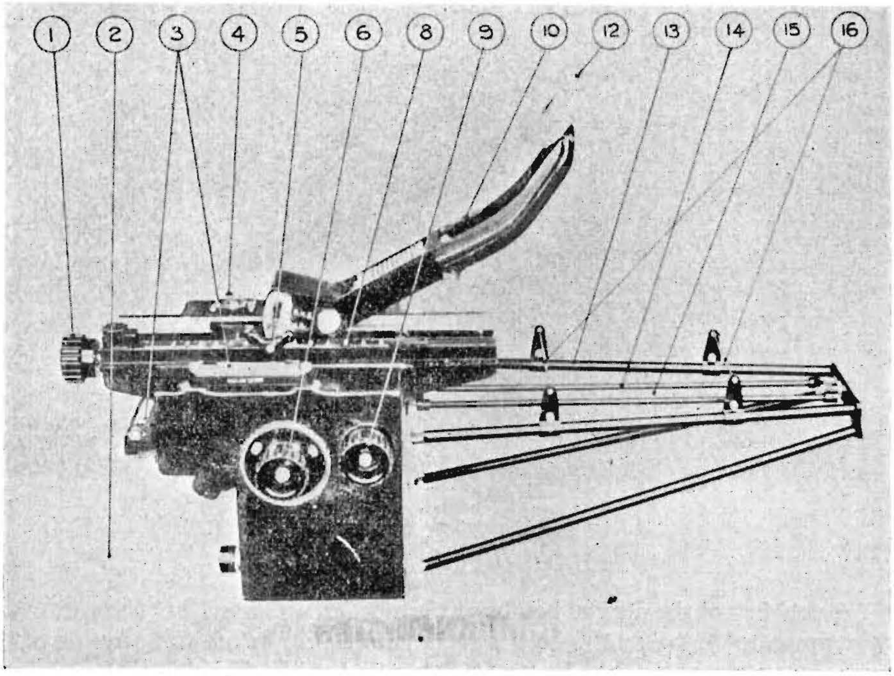
R.A.E. was approached, and, because of the urgency with which the project was viewed at that time, August 1938, suggested as a temporary expedient a method involving the use of the existing course setting bombsights Marks VII and IX.[1] Later in the same year, a special sight which embodied the features noted above, *Scatter Bombsight Mark I*, was designed ; three such sights were ordered for experimental purposes.

So far the approach to the target had been in level flight, but it was soon found that this method was impracticable, and the contract for the sights was cancelled in the following year. A method by which the target was approached in a dive, followed by a short distance of level flight, seemed to be the answer, and a sight designed to meet this new manœuvre, the *Exponential Bombsight*, was soon produced and issued in small numbers.

All was not well, however, with the type of bomb to be used. Several types were advocated, among them a small impact-fired bomb—the 'S' (Scatter) Bomb—to be released in large numbers, or a larger bomb fired by accoustic or photo-electric means. Finally, the problem of designing an efficient bomb became insuperable and the whole project was in consequence abandoned in early 1940.[2]

[1] M.A.P. File S. 45817.
[2] A.M. File S. 43610/3.

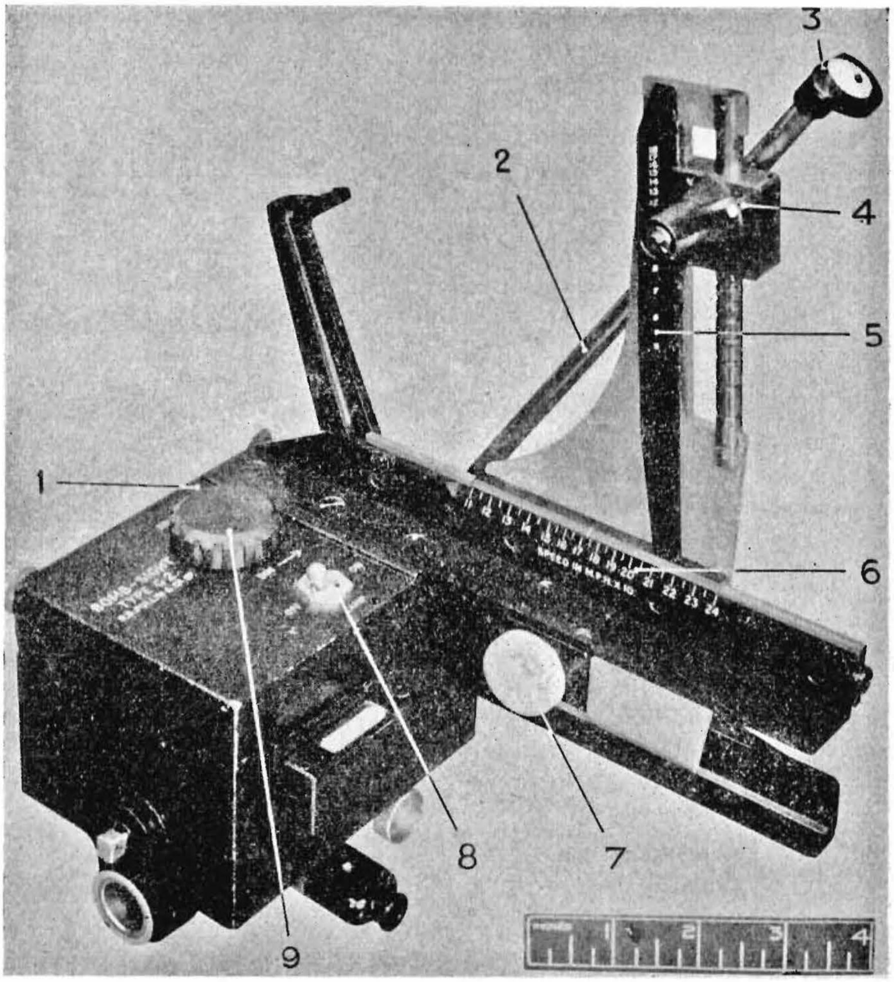




SCATTER BOMBSIGHT. PROTOTYPE AND PRODUCTION MODEL

The Paratroop sight

In 1942 when the training of paratroops began in earnest, difficulties were experienced in deciding the correct moment at which to order 'jump' in order to bring the men into a chosen dropping zone. Some definite indication was obviously desirable and the need led to the development of a type of bomb aimer's sight to be used as a guide to the officer in charge of 'dropping.' The original design was made by a paratroop training station, while the final design of suitable scales and the mechanical details was undertaken by the Royal Aircraft Establishment at Farnborough.



PARATROOP SIGHT

The problem of the normal bombsight is quite complicated, but the paratroops sight presented extreme difficulties ; the initial fall, before the opening of the parachute, resembled that of a low T.V. bomb, but the final fall with parachute open, depended entirely on the prevailing wind speed and direction and the person's rate of descent, the latter averaging some 17½ feet per second. Further complications arose from the fact that it became a practice to ensure opening, by the use of a static line attached to the aircraft ; thus, although the first part of the fall only varied between narrow limits, the latter part varied widely with the height of the jump.

This led to the requirement for a large range of height and speed scales and with it, the attempt to use the same sight for the release of the paratroop equipment containers which were to land within easy reach. The problem thus became so abstruse that the special sight, although designed, never came into service use.

CHAPTER 20

BOMB CARRIERS

Early history

Towards the end of the 1914–18 war, when the carriage of bombs inside the aircraft began to be contemplated, special systems for individual aircraft were designed. Examples of these were the Handley Page and Gledhill types where the bombs were suspended in cells by their noses. But whatever the type all carriers had certain elements in common ; a release hook, known in the service as a release slip ; a framework, attached to some suitable part in the aircraft, which held the release slip ; a wire cable from the release slip to the bomb aiming position in the aircraft, and a lever by which the cable could be pulled. The controls were often duplicated in aircraft which carried an observer, so that either the pilot or observer could release the bombs.

In the tubular carrier a further complication had been added as a requirement for naval operations. It might be necessary to attack a submarine on the surface or under the water, and consequently a method was required to enable the bomb to be dropped so that it would explode on impact if the submarine was surfaced, or alternatively after a short delay if it was submerged. The choice of instantaneous or delay operation was given to the bomb aimer by fitting a direct action pistol in the nose of the bomb and a delayed action pistol in the tail. By means of a second system of wires to the carrier, either the nose or both the nose and tail pistols could be made inoperative. The latter condition was valuable when bombs had to be released, in an emergency, over friendly territory, or if one fell accidentally during loading. This system, known as selective fuzing, was first introduced into tubular carriers and, with many modifications, was still in use in 1945. The light series carrier was a simple means of avoiding the necessity of separate release cables for each small bomb carried, and enabled four bombs to be released, in series, by four pulls at a single cable. Selective fuzing, in this case was not required.

For the relatively small bombs and small bomb loads carried in 1918,[1] used in conjunction with the elementary and inaccurate bombsights of the time, these simple carriers sufficed ; but their mechanical imperfections and uncertain action, made accurate bombing impossible. The first essential of any bomb release system is that the bomb must leave the slip instantaneously at the moment the bomb aimer wishes it to do so—a necessity which increased with every extra mile per hour of aircraft speed. With the system of cables, often of great length and with many changes of direction, this was impossible. Here then was ample room for the improvement of an efficient bomb release system.

Development 1919 to 1939

In a letter to the Ordnance Committee on 29 March 1922 the Deputy Director of Research (Armament) (D.D.R./Arm.), discussing the need for a revised bomb programme, prepared a ' schedule of requirements for embodiment

[1] The 'standard ' bomber of that day carried four 250 lb. bombs, a load not greatly increased for the next twenty years.

in design of a new universal carrier,'[1] which was circulated to fifteen civilian firms who were asked to submit designs and quotations for consideration. Although bombs up to 4,000 lb. in weight were recommended for development at this time, it was obvious that for many years lighter bombs would be in use. Consequently the new carrier was to be made in two sizes: one for bombs from 50 lb. to 300 lb., and the second for bombs between 200 lb. and 600 lb.

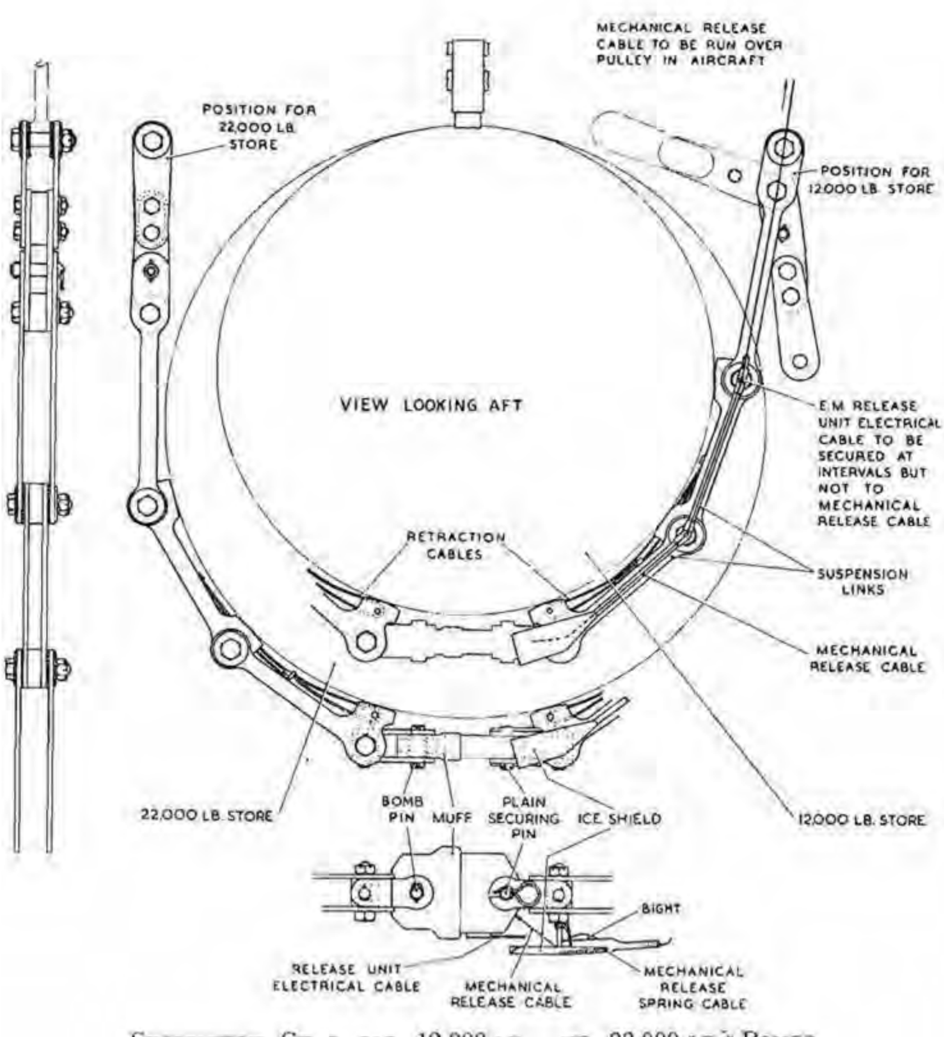
The carrier chosen for development was a combination of the framework suggested by Messrs. Blackburn and the release slip by Messrs. Vickers. The latter was of special interest as it included designs not only for an improved mechanical system, but for hydraulic, pneumatic and electric release, the hook employed being in the form of a double claw. Four experimental carriers were ordered from Messrs. Blackburn in October 1925, and arrangements made to supply four of the new claw release slips to the firm for fitting to the carriers. The complete carriers were to be sent to A. & A.E.E. for test. The trials were held up until July 1926 because the dummy bombs were not available, and it was found that most of the existing and projected bombs fitted the carrier satisfactorily.[2]

This early carrier was little more than a duplication of the old tubular carrier and was unnecessarily bulky and complicated, it offered far more head resistance, and was in fact little improvement on the older types. Even its construction in duralumin found little favour, as corrosion became evident early in the trials.[3] During the following months the carrier went through a series of small modifications and the corrosion had been examined and cured by the firm. It was unfortunate that the firm chose the old tubular type carrier as their model because, although admirable enough in its lightness and neat design, it was not rigid enough to stand prolonged wear and rough usage. The second design by Messrs. Blackburn, commenced in 1927, was based on the channel, section carrier, lightened and modified extensively, but rigid enough in itself to need no duplication of the horizontal members. The new design, known as the Mark II, became the forerunner of the modern bomb carriers, except for those in the largest bomber aircraft where problems of carrying weights up to 10 tons required entirely new designs.

Four of the Mark II design were ready for trial in May 1927. The tests which took place at A. & A.E.E. continued until July, and were reported as satisfactory.[4] Emphasis was placed on the comparative lightness of the carrier and the protective coating against weathering and corrosion appears to have been efficient. The new carrier had been designed originally to carry the new General Purpose bombs, but large quantities of the bombs, used in the First World War, remained, and in September 1927, Messrs. Blackburn were asked to modify the carrier to accommodate them. This meant fairly extensive alteration—lengthening the main channel frame; strengthening the nose and tail steadies; reduction of the distance between the top of the carrier and the aircraft wing, and modification to the claw release slip.

Following static tests at the Aeroplane and Armament Experimental Establishment, it was decided, in November 1927, that the carrier should be re-designed by Messrs. Blackburn. One carrier, ready for tests in April 1928,

[1] *See* Appendix No. 16.
[2] A.M. File 540153/24.
[3] A.M. File 739340.
[4] A. & A.E.E. Report Arm./178, 22 July 1927. A.M. File 734009/26.



SUSPENSION GEAR FOR 12,000 LB. AND 22,000 LB. BOMBS

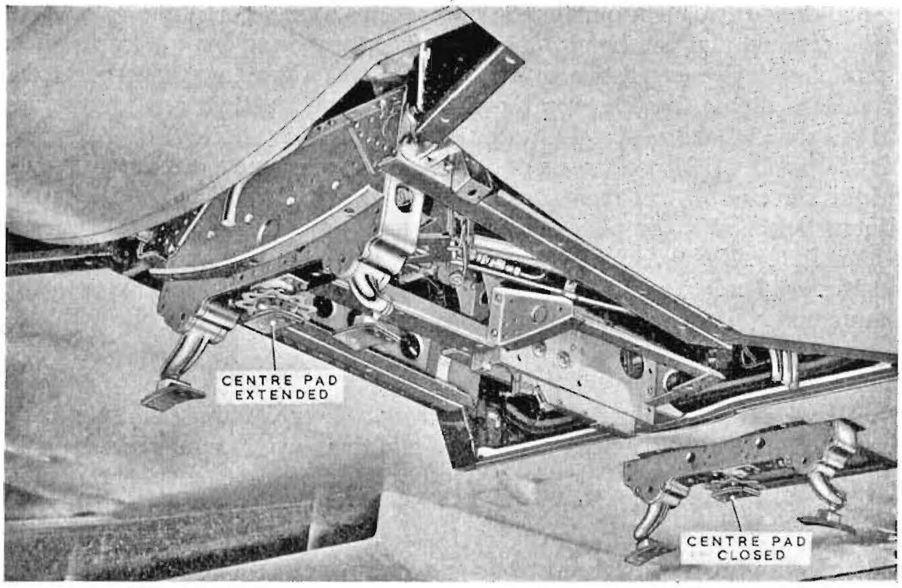
was intended to accommodate all bombs from 50 lb. to 550 lb. and was to replace the two universal carriers previously manufactured. It embodied the same principles as the previous types, but detailed construction had been made more robust, and the direction of pull of both the release and fuzing controls could be altered. The main modification to the release slip was that the new one would cater for all bomb suspension lugs of the standard service and new pattern bombs.[1]

The next month the main carrier member was reduced in length to allow its occupying the minimum overall space in installation for accommodating the 120 lb. range of bombs. The shortened version of the carrier was to be provided with fittings to allow the detached front and rear ends to be readily attached to make up a full length carrier to accommodate the 500 lb. range of bombs. The fuzing tube was to be treated in a similar manner.

[1] A.M. File 734009/26.

Carriers for large bombs

The S.N. Minor bomb was used against targets in Germany in 1918 and a special carrier of the frame type with sling release was designed. One end of the sling was secured to the frame of the carrier and the other ended in a loop which was attached to the release hook. When the release hook was operated the sling swung clear allowing the bomb to drop. The S.N. Bomb was abandoned after the Armistice and the demand for a new and well designed carrier for large bombs did not arise. Effort was concentrated on the 50 lb. to 500 lb. General Purpose series of bombs resulting in the very efficient universal carrier already described.



1,000 LB./2,500 LB. BOMB AND TORPEDO CARRIER, MARK II

In 1930 the Royal Aircraft Establishment (R.A.E.) were asked to design a carrier to accommodate the proposed 1,000 lb. and 2,000 lb. General Purpose bomb ; the newly designed ' B ' bomb (1,100 lb.) ; and the 1,500 lb. Armour Piercing bomb, but no carrier was made and the scheme appears to have been shelved until 1936, when there was a requirement to carry the 2,000 lb. Armour Piercing bomb in a Whitley. The design, produced by R.A.E., was ready in October and embodied a cartridge fired release slip and double sling. By this time the 1,000 lb. and 2,000 lb. G.P. bomb and the 1,500 lb. A.P. bomb were no longer an Air Staff requirement and the new carrier was designed solely for the 2,000 lb. A.P. bomb.

At this period new designs of heavy aircraft were being prepared by the leading aircraft firms and bomb stowage was to be inside the aircraft in specially designed and sealed compartments. The Director of Operational Requirements (D.O.R.) was most anxious that the design of a large carrier to take loads up to 2,000 lb. should be standardised as far as possible,[1] and, realising that there might be certain aircraft into which such a carrier could not possibly be fitted,

[1] A.M. File S. 39545.

he advocated close co-operation between the Armament department of the Royal Aircraft Establishment and the aircraft firms, and that certain aircraft designers should design their own carriers.

The design of the carrier continued at R.A.E. during 1936 and 1937, the delay being largely caused by numerous discussions with aircraft firms. By this time Messrs. A. V. Roe had designed their own carrier for the Manchester and had obtained permission for its installation. Messrs. Blackburn also were permitted to build their own carrier for the Botha, and Bristol Aeroplane Co. their own design for the Beaufort. It should be noted that the R.A.E. design, by suitable adjustments, could take either a bomb or torpedo, and consisted of a single steel channel member with fixed nose and tail steadies. In the original design two electro magnetic release slips were secured one to each side of the channel and the bomb or torpedo was supported by two cable slings. A straining device, consisting of a worm and wheel gear, was incorporated in the release slip so that the bomb could be brought up tight against the nose and tail steadies and held rigid by the slings.[1]

By December 1937 production of the new carrier became a matter of urgency, and the Director of Armament Development (D.Arm.D.) insisted on the supply, without delay, of a complete specimen before large-scale production was put in hand. The Royal Aircraft Establishment were unable to meet the demand and Messrs. Aerolex and Messrs. Avro Aircraft Co. were each commissioned to manufacture three models for experiment.

Carrier for internally stowed bombs

Air Staff were confronted with the problem of bomb stowage in a number of new aircraft in 1937. The manufacturers had their own individual ideas on the subject, but it was obvious that some standard form of carrier should be adopted. In the past the externally fitted carriers on small aircraft had presented no loading problems; they were near the ground in exposed positions where loading and adjustments to crutches and fuzing links could be made without difficulty. The disadvantages were, of course, the exposed position of the bomb load, and its effect on the performance of the aircraft. It was a natural step in the development of the new and larger aircraft, to provide internal stowage in the wings and fuselage. The size of these 'bomb bays' was limited by the structure, and accessibility had to be sacrificed in order to obtain the biggest bomb load.

The major problems were not only that of hoisting the bombs through greater heights into the bomb bay, but also engaging the bomb suspension lug on the release hook and adjusting the crutches and fuzing links with ease and certainty in the confined space. The Air Staff were fully alert to the problems of internal bomb stowage and their first requirement was formulated in January 1937.[2]

The problem of 'Bombing up' from all its aspects was dealt with by the Bombing Committee, under the chairmanship of Air Commodore W. S. Douglas. There were three proposals as to how this should be done :—

(*a*) By lowering the bomb release slips only.

(*b*) By lowering the complete carrier.

(*c*) By having complete sets of duplicate carriers.

[1] A.M. File S. 30261.

[2] *See* Appendix No. 17 and A.M. File S. 40175.

Bomber Command were in favour of (*c*) and were supported by the Assistant Director of Research and Development (Armament) (A.D.R.D.(Arm.)). The Armament Group opposed both (*b*) and (*c*) and said that the group had given a great deal of consideration to this important question and the suggestions, although they might be considered revolutionary, had been carefully studied. Briefly they were covered by (*a*) with a simpler form of bomb carrier than the Universal type, and which would provide that all the principal elements of the carrier should be built into the aircraft.

After considerable discussion, the chairman, summing up, said that 'the general consensus of opinion in the committee was that until something drastic was done to simplify the design of bomb carrying apparatus, method (*c*)—duplicate carriers—was the most practicable one from the operational point of view, and that for aircraft of the near future it would have to be adopted. Method (*a*) lowering the release slip—should be borne in mind when considering future design of bomb carrying installations. The recommendation of the committee would be that in future types of aircraft, a built-in system of carrying bombs, such as had been described by Armament Groups, should be attempted.'

The bombing committee also discussed the problem of Bombing-up a squadron of heavy bombers, and although this has no direct bearing on the present subject, it is mentioned here to indicate the size of bomb load envisaged in the minds of the committee at that time, which were quoted as follows:

(*a*) A heavy bomber squadron of the near future—total load 160 by 250 lb. bombs.

(*b*) A heavy bomber squadron of the more distant future—total load 300 by 500 lb. bombs.

The minimum time available for bombing up on the landing of an aircraft—that is the minimum time available for a 'turn-round' of the aircraft—would be two hours. After discussion this was increased to four hours.

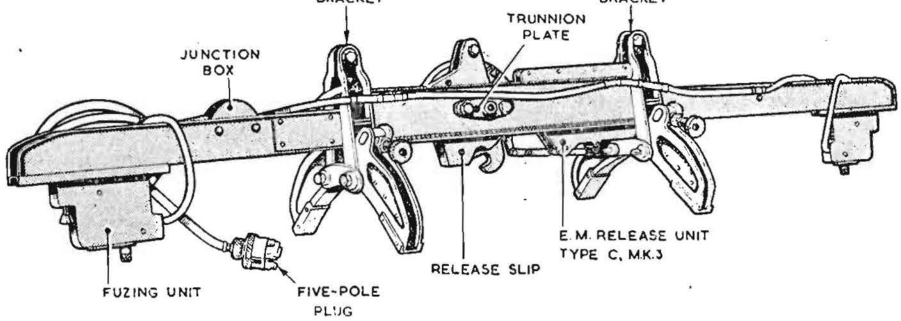
By April 1937 the aircraft firms had prepared designs of carriers. Messrs. Supermarine favoured a separate carrier complete with steadies, but built into the wing structure with the release slip on a light bar which held the fuzing boxes and was lowered by a winch. These bars were fitted with light type steadies so that bombs would not tend to swing, and so bend the fuze setting control links, during hoisting. Messrs. A. V. Roe had devised a scheme of racks on transverse bars, lowerable and detachable, the racks being movable on the bars to allow alternative stowage of 500 lb. or 250 lb. bombs. The suggested method was to load three or four bombs to each set of racks, complete the fuzing, and hoist as one unit. The transverse bars had a cone adjustment to the floor members, with either a snap catch or screwed locking device. Messrs. Handley Page had made 'general arrangement' drawings of part fuselage and part wing stowage with separate racks for each bomb, to be lowerable complete by winch.[1]

A representative of the aircraft firms attended a meeting in July 1937 to discuss further developments in the carrier designs and, if possible, to reach agreement on a standard carrier. The three carriers were discussed and the firms explained what would be entailed in attempting to instal carriers other than their own, but it was confirmed that the design of carriers for internal stowage was closely related to the aircraft design, and when this had been

[1] A.M. File S. 40175.

decided, with a view to taking a particular type of carrier, the installation of another carrier could not be made without serious structural alterations to the aircraft. A full examination and discussion of the features of various carriers which had been produced in the last year took place under the chairmanship of the Director of Armament Development (D.Arm.D.) in December 1937. In view of the defects and the improvements effected, and still possible, with the readily detachable type of carrier, it was recommended that further investigations on the built-in type should cease. The Air Staff requirement was revised[1] and issued to firms interested in this work. A working 'mock up' carrier was to be produced by 1 May 1938.

Two of the interested firms had already produced practically what was wanted and it was known that several other firms were well advanced in designs which appeared to be promising. The object of competitive development was to obtain as large a selection of carriers as possible from which to choose. The development period was subsequently extended until 27 May 1938 and type designs were prepared by five aircraft companies, Messrs. Shorts, Handley Page, A. V. Roe, Armstrong Whitworth and Vickers.



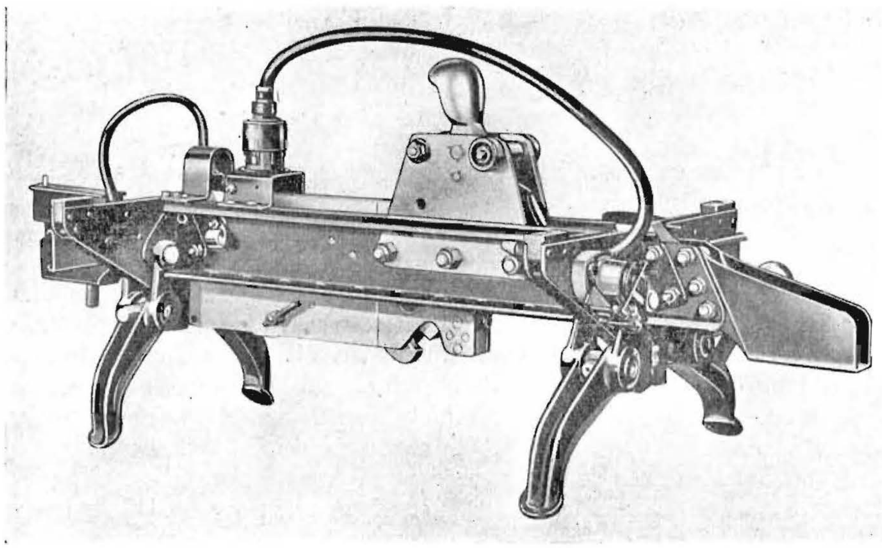
UNIVERSAL BOMB CARRIER. MARK III

A conference was held at the Royal Aircraft Establishment (R.A.E.) on 27 June 1938, to reach a decision concerning the most suitable carrier for selection as the standard R.A.F. type. The operational properties as regards bombing up were demonstrated and it was unanimously agreed that the design of carrier produced by A. V. Roe & Co. Ltd., met the specification generally. The design submitted by Messrs. Shorts, however, had many good features and if the crutch adjusting mechanism could be re-designed, there would be little to choose between the two designs.

Operational and strength tests of the A. V. Roe carrier were carried out at the Royal Aircraft Establishment and in their report it was considered that the carriers and housing were satisfactory from the operational point of view, and that the bomb carriers and housing were suitable for installation in new types of aircraft of any normal construction.[2] The carrier was introduced into the service on 16 June 1939. In general the carrier resembled the 250–500 lb. universal carrier and consisted of a 'U' shaped channel to which were attached the front and rear crutch lever brackets, the E.M. Release Unit and single hook release slip.

[1] A.M. File S. 43278.
[2] R.A.E. Report No. Arm. 35 and A.M. File S. 43278.

A swivelling bayonet fitting was provided for the winch cable. Lateral extensions were provided on the brackets to form a horizontal platform and served as reaction points when the bomb carrier was stabilised after being secured in the housing. The crutch levers were adjusted by means of a left- and right-handed screwed shaft engaged in the crutch levers and operated by a handle. The fuzing arrangements were similar in principle to the Universal carrier, being carried either in the channel or underneath on slides. The carrier housing which was built into the aircraft structure contained the carrier securing hook and stabilising mechanism. When the carrier was secured in the housing, it was stabilised by operating a handle incorporated in the bomb winch. This caused two levers to act on reaction points of the carrier thus holding the bomb and carrier steady.



AVRO TYPE (STANDARD) 100/1,000 LB. BOMB CARRIER. MARK 1 A.N.

The release slip

So far attention has been concentrated on the framework of the carrier, but this was merely a framework to hold the bomb rigid and to accommodate the fuzing and release mechanisms. It is now necessary to trace the history of the release slip up to the year 1938.

The methods of releasing bombs, up to the end of the 1914–18 war, had developed from the simple expedient of dropping the bomb overboard by hand, to the more or less satisfactory release hook operated by a length of wire. The design of a release mechanism presents two conflicting problems : it must retain the bomb securely under all conditions of flight, but must release it with certainty at the right moment. As the size and weight of bombs increased, these requirements became more and more exacting.

To make the bomb more secure presented little difficulty, but the need for a mechanism which would release bombs with certainty and instantaneously, grew with the progress of bomb sighting. It is not surprising, therefore, that even in 1945 the temporary or permanent ' hang up ' of a bomb might have occurred, for although the need for security had become so great, the power available to operate the release had been reduced tremendously. In the place of a vigorous pull on a lever or toggle, which either released the bomb or broke the equipment, was substituted the feeble pull of an electro magnet.

Vickers claw release slip

It is rather unfortunate that in the search for a safe yet sensitive release slip for the universal carrier, the early designers abandoned the well established, reliable and simple single hook, which had been in use for over ten years, and concentrated their efforts on an elaborate double claw release. Instead of the single pivoted hook, two claws were locked together by a central plunger and two toggles. The weight of the bomb rested at the junction of the claws, which were freed when the central plunger was depressed. Experiments with this type continued until 1933, when it was generally abandoned in favour of the single hook in a modified version of the release slip which had proved successful up to 1926.

Cartridge firing device

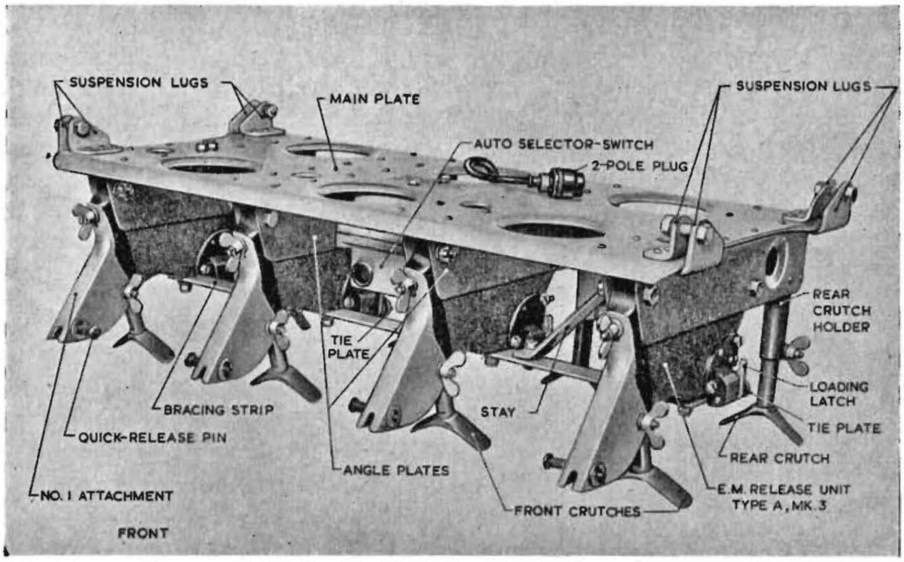
With the improvements of bomb sighting methods, which developed steadily from 1918 onwards, came the demand for a release which would operate instantaneously or as near so as could be devised. This meant abandoning the hand-operated devices and using electric power. In the early stages of development no efficient mechanism could be found to convert the small current available into sufficient energy to release the comparatively heavy bomb. Messrs Vickers produced a cartridge firing device consisting of a small cordite charge electrically fired, which, on explosion, operated the release slip. Failures occurred for a variety of reasons, and the history of the release showed a continuous series of modifications and improvements. The mechanism had to be frequently dismantled and cleaned, and contact faces carefully stoned smooth as the slightest burr or trace of grit caused failure. The explosion chamber and the gas vents needed cleaning after each drop, and the electrical contacts continuously needed repairing. This was a violent, clumsy, rather dirty and generally unsatisfactory arrangement. Certain squadrons discontinued the use of this form of release and relied upon the emergency mechanical release only. It had but a short life, and needs no further mention.[1]

Electro magnetic release

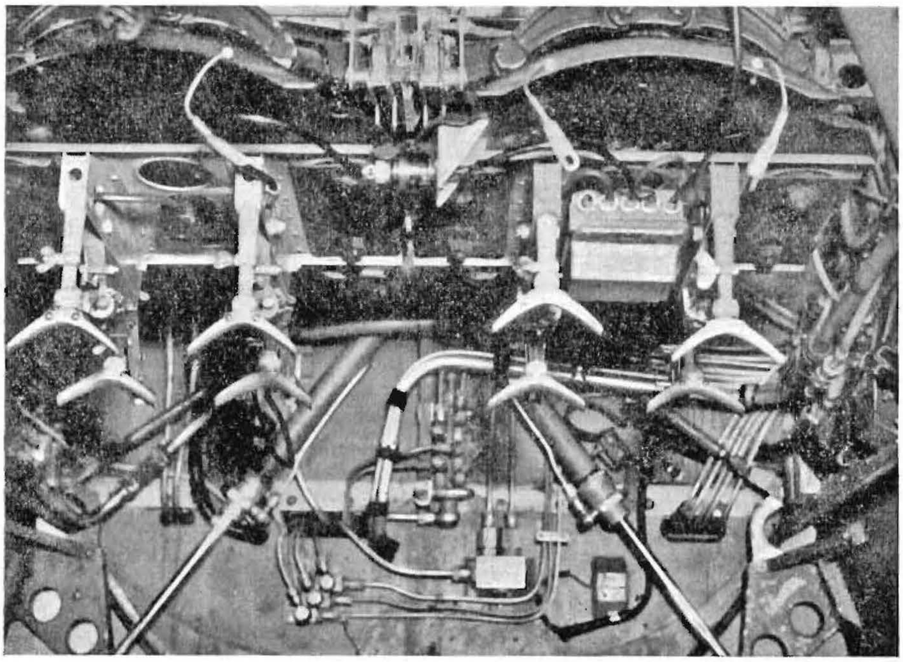
Messrs. Vickers of Dartford designed and manufactured a release gear which was operated by electro-magnets. Preliminary trials were carried out at the Aircraft and Armament Experimental Establishment (A. & A.E.E.) in July 1931, and the unit functioned satisfactorily during rough taxying and heavy landing. There was, however, a slight delay in release during low temperature tests, which was rectified by fitting a stronger release spring. Early in 1932 Vickers were asked to fit the release to the skeleton tubular and light series carrier, and an indicator lamp switch was incorporated in the unit to enable the electro-magnetic unit to be interchangeable with the cartridge fired release. A number of carriers were modified and were sent for trials in the service for comparison with carriers fitted with cartridge fired release mechanisms which were undergoing trials at that time.

[1] A.M. File S. 30261.

The service trials revealed some minor defects, but the Electro Magnetic (E.M.) unit was more satisfactory than the cartridge fired type. After the defects had been corrected by the makers, the units were given an intensive trial at A. & A.E.E. covering a period of fourteen days at the end of 1932. The test

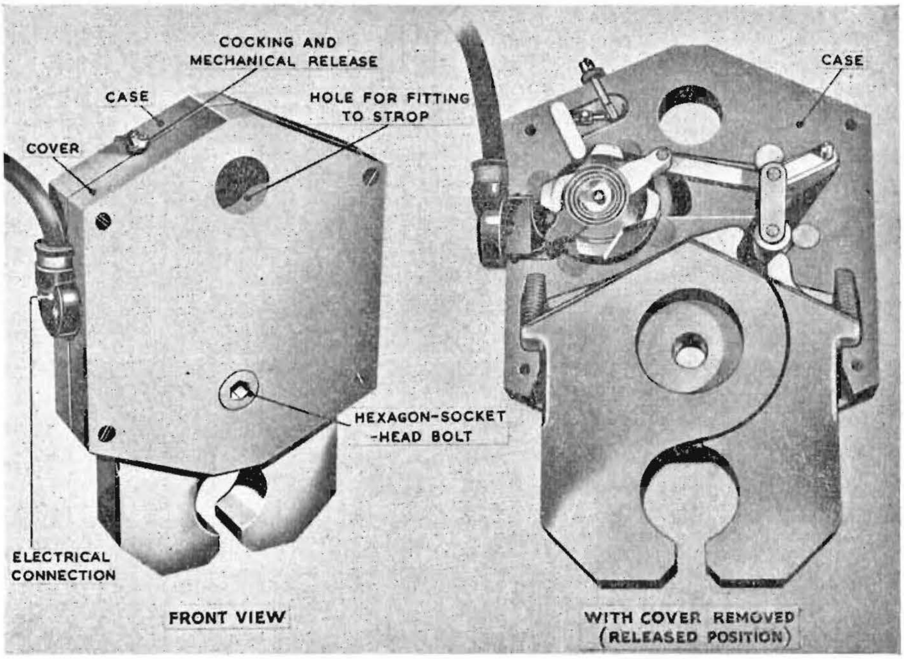


LIGHT SERIES BOMB CARRIER. MARK III



LIGHT SERIES BOMB CARRIER WITH AUTOMATIC BOMB SELECTOR, INSTALLED IN MOSQUITO AIRCRAFT was severe ; five hundred bombs were dropped and ground trials included functioning tests after being subjected to an artificial sand storm and also during and after immersion in water. The release functioned efficiently during these trials, but there were failures during the high altitude test after flying through snow clouds at a temperature of minus 38° C. The makers again modified the unit, this time making the mechanism totally enclosed.

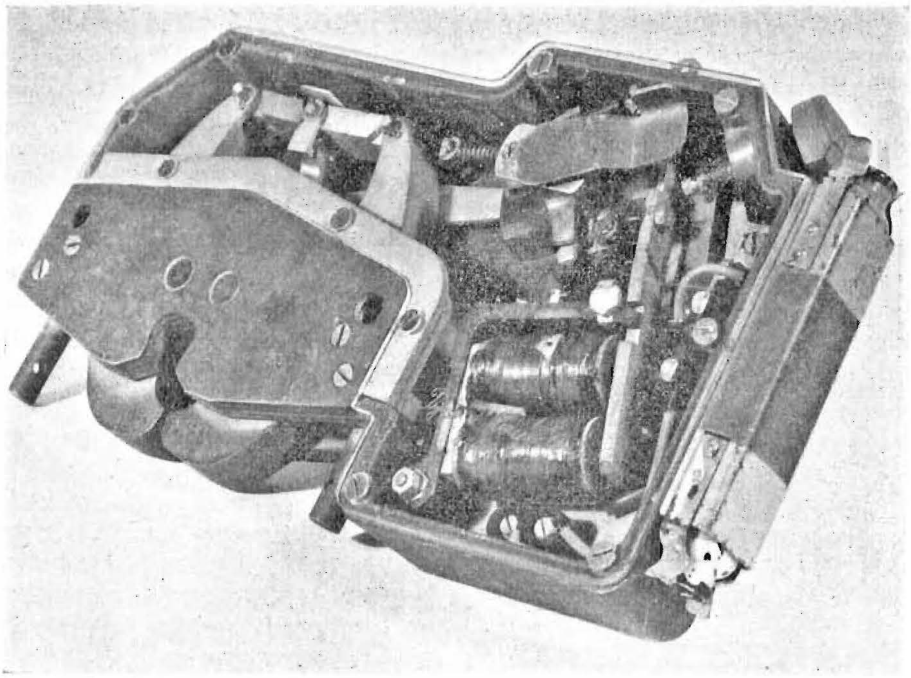
A light carrier was designed by Vickers which incorporated a new form of release slip actuated by an E.M. unit which was similar to the one fitted to the larger carriers. Tests were carried out in April 1933, and the releases were actuated eight hundred times, failures again occuring under very low temperature conditions. Air tests were completed January 1934 and the carriers were sent for service trial at an Armament Training camp. During six months of use the releases operated successfully, and as the release units of light carrier were essentially the same as the heavy carrier, the trials ran concurrently.



ELECTRO MAGNETIC RELEASE UNIT. TYPE ' J '

During the next two years the release unit was modified several times. The clearances between the release levers in the mechanism were critical, and after continued use they were found to change. This was rectified, at first by fitting a magnet positioning plate, but later the body of the release was constructed in aluminium instead of bakelite. The light series carrier was sand-proofed by the addition of felt shields, and after further service trials the design was approved for introduction into the service in January 1938.

The E.M. release unit was fitted to the torpedo carrier in 1935, and after extensive trials at experimental establishments and in the service, the unit was approved for use with the single sling mechanism and single hook release on the 2,000 lb. carrier designed by the Royal Aircraft Establishment (R.A.E.).



Electro Magnetic Release Unit. Type 'P'

Electro magnetic fuzing

The selective fuzing of bombs had been carried out by means of a cable running over pulleys, and, with the development of electrical release of bombs, it was an obvious step to operate the fuzing electrically. Messrs. Handley Page produced a number of electro magnetic fuze operating devices in April 1933 which could be used in conjunction with either of the electrical bomb release systems undergoing trial at that time. The first design was not suitable, but by October in the same year, the unit had been re-designed, tested and approved for use in the Heyford aircraft. After further tests fitted to universal carriers the units were given extended service trials in 1935. Three years later a design manufactured by Automatic Telephones and Electric Co. was tested and found superior to the existing type, due to simplified and more robust construction, and was cheaper to produce in quantity.

Bomb Distributors

As the design of aircraft advanced, giving a larger bomb load, the problem of how to use the bombs to best advantage was given much consideration. Early in 1931 the A.O.C.-in-C., Air Defence of Great Britain (A.D.G.B.), wrote to the Air Ministry suggesting that it would be advantageous to study the different method of bomb dropping by formations of aircraft.[1] A fully trained bomber formation, composed of aircraft flying fixed distances apart and dropping bombs on a signal from the leader, should always result, theoretically, in a fixed pattern of bomb bursts. Also, if suitable electric bomb releases, variable for ground

[1] A.M. File S. 30216.

speed of aircraft, which allowed bombs to drop at stated distances apart were used, a single aircraft with a trained crew and carrying ten bombs should be able to ensure one hit on a narrow target such as a bridge or railway line.

The method adopted was to eliminate the range error, to which the bombing crew were liable, by dropping the bombs from one or more machines at predetermined time intervals, resulting in the spacing of the bombs within the target area. Similarly, line error was eliminated by extending the front of the attack by using a suitably arranged formation. To achieve this an accurate and reliable gear for automatically distributing the bombs at predetermined time intervals was required. The bomb release gear would have to be instantaneous in operation and reliable; the failure or delay of one bomb of a 'stick' to release would spoil the pattern and could result in missing the target. Accurate formation flying was also required to ensure correct spacing of the bombs.

Early types

The Royal Aircraft Establishment (R.A.E.) was given a free hand in the construction of a suitable bomb distributor, and the first instrument was completed in October 1931. It was constructed of automatic telephone apparatus and had a speed range of one bomb in two seconds to eight bombs a second.

Following a demonstration of the distributor at Gosport in February 1932, Headquarters of the Air Defence of Great Britain (A.D.G.B.), requested that fourteen sets should be supplied to No. 12 Squadron for service trials. The instrument demonstrated was far from perfect in operation, and had to be extensively modified before it was suitable, and owing to the urgency, it was decided to have the distributors manufactured by the trade[1] to drawings prepared by the R.A.E.

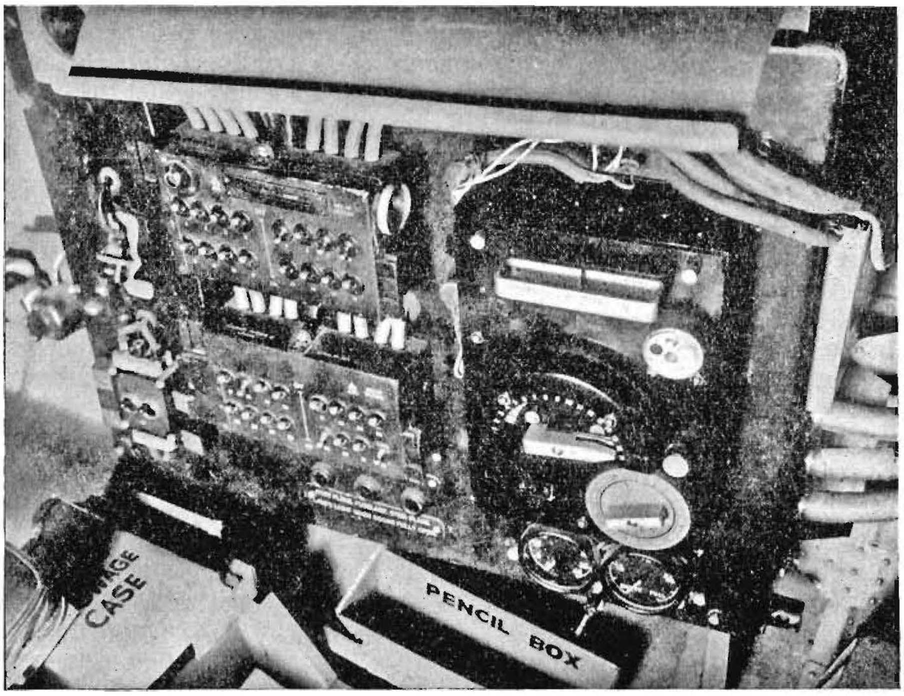
The distributors were fitted to 'Hart' aircraft of No. 12 Squadron, and were used in conjunction with the cartridge fired release slips which had recently been produced for service trial. The distributor consisted of a small box containing a clockwork motor which moved an arm at constant speed across a series of contacts embedded in vulcanite. Each contact was electrically connected to the release unit, and as the arm touched a contact the circuit to the bomb carrier was completed and the bomb released. The contact strips were so positioned that by moving the contact on the operating arm the interval between the making of the circuits could be varied between one to three and a half seconds.

During the trials at No. 2 Armament Training Camp at North Coates Fitties, a maximum variation between the calculated and actual spread of the bombs of 1 yard plus to 60 yards minus, was recorded. These errors were due partly to the distributor and partly to other causes, such as delay in operation of the cartridge fired release gear. Several modifications were suggested by A.D.G.B., but a distributor so modified did not arrive at the Training Camp until the end of the trials and was not tested.[2] After investigation by the makers it was found that it was impossible to modify the existing distributors to meet the requirements of A.D.G.B., and a completely new design was prepared.

[1] A.M. File S. 30216.
[2] A.M. File S. 32141.

Automatic bomb distributor, Type IVA

The schedule of requirements of an automatic bomb distributor, drawn up in January 1934, contained several new ideas. It had to be operated by a push button release fitted to the control column, for operation by the pilot, and it had to be possible to drop the bombs in a stick by means of an automatic distributor, or to release all bombs together; or to release bombs singly as single shots. The interval between bombs had to be easily adjustable and was to contain an adjustable delay action controlling the starting of the release. The interval between release of individual bombs, was to be variable to give spacings between 9 feet at a ground speed of 200 m.p.h. and 180 yards at a ground speed of 60 m.p.h.; the delay action to be adjustable between 0 to 60 seconds in intervals of 1/10 second.[1]



Bomb Distributor and Selector Switches

It was not until April 1935 that a prototype was ready. The automatic bomb distributor and pilot's control panel, was demonstrated to members of a conference held at the Royal Aircraft Establishment, with the unit being connected to two light series carriers with electro-magnetic release units. The equipment satisfied the requirements to which it had been designed, but was too elaborate and bulky.

In order to make the apparatus simpler and more compact it was agreed to modify the requirements to a speed range of 100 to 200 m.p.h.; spacings of 20 to 360 feet; and delay of 15 seconds. An accuracy of 5 per cent. was required. A modified version of the distributor used at the Training Camp known as the Type IVA was approved for introduction into the service in June 1935 for limited use pending the design of a distributor with delay setting.

[1] A.M. File S. 30216.

Type V distributor

The manufacturers were informed of the new requirements in October 1935; the distributor was to be constructed so that it could be moved from one position to another, *i.e.*, from the prone position to the air gunner's firing position.[1] Nearly a year later the requirements were amplified and, although the distributor need only release eight bombs in a stick, it was necessary to release successive sticks of eight bombs up to a maximum of four sticks. This meant that the distributor would have to automatically set itself to the same setting after use, and incorporate a switching arrangement to connect the selected bombs to the distributor contacts. For aircraft carrying up to sixteen bombs, the selector switches were to be integral with the distributor.

The first complete unit of the new type automatic bomb distributor was forwarded to the R.A.E. for examination in June 1937. The unit was driven by a series wound electric motor which moved the contact bar through spur gearing and two screwed shafts; the angular setting of the contact bar determined the spacing of the bombs. A second field winding provided the reverse running for re-setting, whilst a governor which moved the brushes was intended to control the forward speed. The accuracy of bomb spacing was very poor, in some cases the intervals were so irregular that two bombs could be dropped together or in the wrong order. The delay setting was inaccurate and unreliable due mainly to the very poor speed control of the type of motor used.

Re-design of the distributor was discussed at a conference on 26 October 1937 under the chairmanship of the Deputy Director of Research and Development (Armament) D.D.R.D.(Arm.). At this meeting the Naval Staff stated their requirements which were for 16 bombs; no delay, and accuracy of 15 per cent. To increase the accuracy a larger motor was suggested, and as this meant an increase in the size of the apparatus, it was agreed that the selector switches should be separated from the distributor.

At that time it did seem not possible that one distributor could be made to meet the requirements of the Air and Naval Staff, but towards the end of 1937 the requirements of the Admiralty and Air Ministry were drastically altered, and the only difference between the two types would be the marking of the setting dials. The Naval Staff required the instrument calibrated in time between each bomb, whereas the Air Ministry required calibration in terms of air speed and spacing.[2] The instrument was required to run straight through from No. 1 to No. 16 without a stop, and also to run from 1 to 8 and from 9 to 16 by two separate manipulations of the firing switch. The change-over was to be contained in the instrument; interchangeable parts could not be accepted.

By January 1938 drawings of a distributor which would meet the requirements had been prepared. It was similar to the Type IVA except that it had sixteen contact strips instead of eight. The selector switches were separate from the distributor proper and in this way the switches could be fitted in the pilot's cockpit and the distributor placed in the bomb-aimer's position or anywhere convenient. A drum switch was incorporated in the selector switch box which had four positions—' Safe,' ' Single and Salvo,' ' Distributor ' and ' Container.' The requirement for the two separate sticks of eight bombs each was, however,

[1] A.M. File S. 30216.
[2] A.M. File S. 36452.

cancelled in February after inspection of the new distributor, and bench tests of the prototype, carried out at the Royal Aircraft Establishment (R.A.E.) in May, revealed that several minor modifications were required before the apparatus was suitable for type trial.[1]

Preliminary reports on the type trial indicated that the apparatus was satisfactory and production was considered. It was considered, however, that the distributor was not susceptible to quantity production, and as an alternative a distributor on the automatic telephone principle which could be easily produced and consist mainly of standard automatic telephone components was proposed.[2]

Type VI Distributor

A prototype of the new design distributor was ready for trials in October 1938, and bench trials were carried out at the Aeroplane and Armament Experimental Establishment (A. & A.E.E.) later in the same month. The instrument was found to be accurate, easy to manipulate and robust in construction, but modification was required to the variable speed drive to prevent slipping.[3]

The mechanical part of the instrument was entirely different to previous types, the principle being a variation of the speed of the contact arm over fixed contacts, instead of a constant speed arm moving over variable contacts. The driving mechanism consisted of a constant speed wheel to which was attached the contact arm, driven by a clockwork motor, and connected by means of an idle pinnion roller to another wheel which drove the speed governor. Variations in speed of the contact arm were obtained by moving the roller in relation to the axes of the two wheels by means of a rotatable disc graduated with the spacing scale.

The distributor, known as the Type VI, and used in conjunction with the selector switch box, was recommended for introduction into the service by the Aircraft Equipment Committee (A.E.C.) in November 1938.[4] Thermostatically controlled heaters were fitted to the mechanisms in May 1940,[5] to prevent slowing up during extreme cold. In order that a stick of twenty-four bombs could be released from Stirling aircraft, a distributor similar in design to the Type VI, but having thirty-two contacts, was developed and known as the Type VII.[6]

Type VIII Distributor

Early in 1943 the Pathfinder Force required a special distributor for use in their aircraft in order to drop flares at time intervals of from two to eight seconds. The Royal Aircraft Establishment (R.A.E.) modified a piece of existing equipment, the Type 35 Camera control, which could be attached to a standard Type VI distributor without modification to the aircraft.[7] The Type 35 Camera control was designed to operate an aircraft camera at pre-determined intervals. It was driven by a compact electric motor which operated switches

[1] A.M. File S. 43893/1.
[2] A.M. File S. 43893/2.
[3] A.M. File S. 45555/1.
[4] A.M. File S. 45555/2.
[5] M.A.P. File R.A. 2219/3.
[6] Aircraft Equipment Committee submission 919.
[7] M.A.P. File S.B. 46336.

at the desired time intervals and these pulses were made to operate the normal bomb distributor. The equipment was approved for introduction into the service in September 1943, to be fitted to aircraft of the Pathfinder Force.

Pre-selector Unit 16 and 32 point

Due to the complexity and variability of bomb loads being carried in new aircraft, the operation of selecting the bombs was rapidly becoming too complicated to be carried out correctly in the different conditions which often existed in the target area. Bombs had to be dropped in definite sequences, according to the load carried, for reasons connected with the centre of gravity of the aircraft. Each new bombing requirement necessitated a complete rewiring of the bomb release circuits, and at no time was the circuit readily adaptable to any other system. As an example, each Wellington aircraft required four special plug blocks to connect the releases to the distributor, and six plates to mask the selector switches leaving only those in use operable.

A device was designed in June 1940, by a technical officer in the Research and Development (Armament) (R.D.Arm.) branch of the Ministry of Supply, consisting of a number of rotary wheel switches making contact with a series of bars with which it was possible to connect any release slip to any selector switch. All the bomb aimer was required to do was to select all the switches (irrespective of the load carried) for stick bombing, or select switches in numerical order for precision bombing.

The instrument was set on the ground when the machine was bombed up and did not need operation in flight ; consequently it could be fitted in any position in the aircraft without modification to the aircraft structure. The unit was approved for service use in October 1940, two sizes were made :—the sixteen point for aircraft carrying up to 16 bombs and the thirty-two point for larger aircraft.[1]

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[1] M.A.P. File S.B. 7064.

CHAPTER 21

BOMB TROLLEYS AND WINCHES

Bomb trolleys

The initial method of loading bombs involved the use of a horse-shoe shaped frame on a two-wheeled Morris trailer which was equipped with small winches to hoist the bomb into position, and could of course only carry one bomb. The Bombing Committee discussed at great length, in 1937 and 1938, suggested methods of 'Bombing Up' a heavy bomber squadron. In the main two systems—known as Method 'A' and Method 'B' were fully investigated. In the former the bombs were unloaded on to the ground and the aircraft positioned over them, and in the latter, trailers loaded with bombs were manœuvred under the aircraft and loaded direct from the trailers.

Arguments in favour of Method 'A' was that the bomb load could be positioned on the ground either prior to take-off or in between sorties, and in view of there only being single bomb trailers, would eventually speed up the operation of bombing-up. Against this the adherents to Method 'B' decried the extra manpower and activity needed firstly to load the bomb on to the trailer; secondly to unload it on to the ground; thirdly to direct aircraft in correct position over the bombs, assuming they had been laid out correctly, and finally hoisting on to aircraft. Method 'B' it was stated would completely avoid two of these operations and half of a third, and make actual loading easier. Time wasted by using only one trailer could be avoided by the production of a large number of trailers, the majority of which would carry more than one bomb.[1]

The method finally adopted and used throughout the period under review, was that of specially designed bomb trolleys. With one exception, the type 'H' for large M.C. bombs, all the trolleys were possessed of the same basic features; a low rectangular chassis, with adjustable chocks to locate the bombs, and small pneumatic tyres. This equipment stood up well to arduous treatment during the war years and serviceability was only affected by the stoppage of spares—notably tyres, tow bars, and brake gear.

The normal method of use was to load the trolley with its complement in the bomb dump by means of rolling, crane or overhead gantry fixtures; tow the loaded trolley to the fuzing shed, and when the fuzing operation was completed tow the trolley, or train of trolleys direct to the aircraft. Being very low structure the trolley could be manœuvred under the aircraft and the bombs hoisted, or 'offered up,' to the carriers direct from the trolley.

Prior to 1942, only one trolley—the type 'A' designed to carry a maximum load of 500 lb. weight, was in general use. By the beginning of 1942, however, two other types were accepted as the standard trolleys; the type 'B' capable of carrying four 500 lb. bombs, and the type 'D', which was specially designed for operation with Wellington, Lancaster and Halifax aircraft, for one 4,000 lb. bomb.

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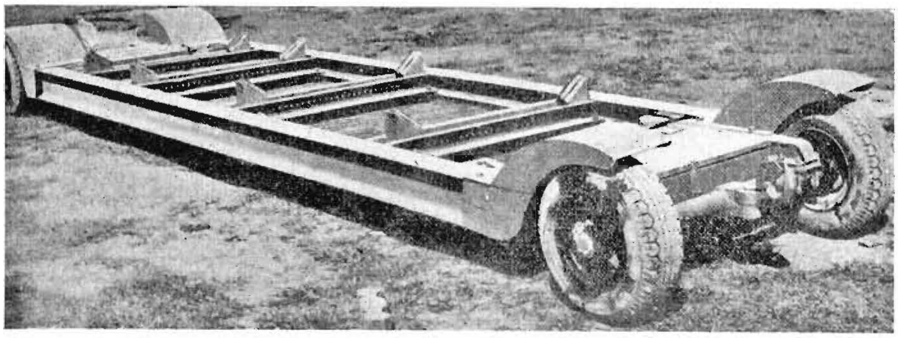
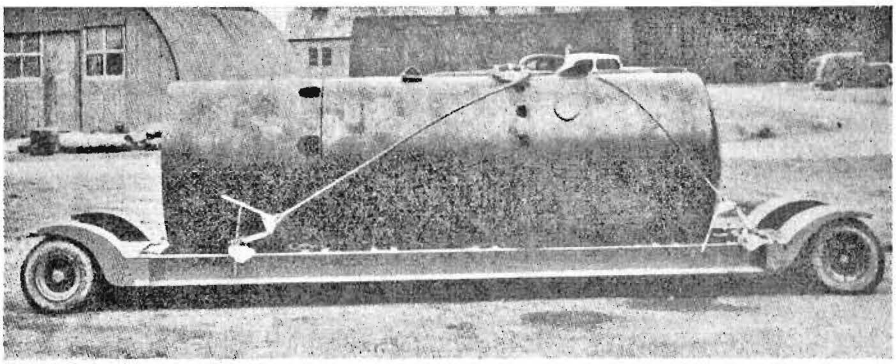
[1] Bombing Committee Papers No. 13.

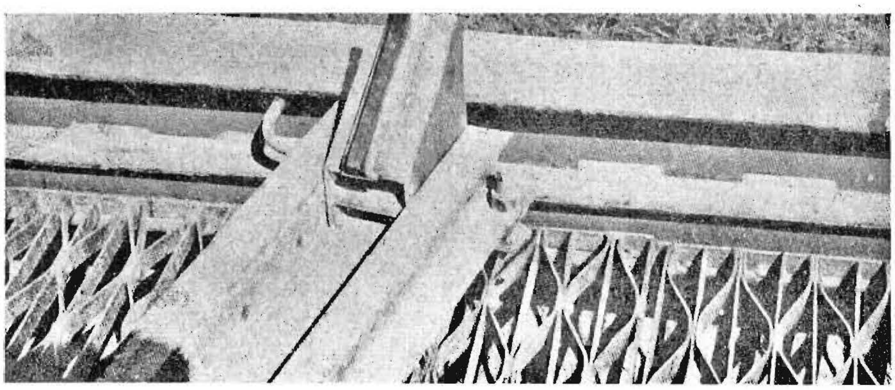
The size and weight of bombs, and the maximum carrying capacity of the operational aircraft, was however increasing and the Type ' B ' was gradually replaced by Type ' C ' with a maximum load of 6,000 lb., and Type ' F ' which took a greater load of 8,000 lb. weight. The two latter types were of ' universal ' application, that is to say, their load could consist of a number of missiles, governed by lineal dimensions, provided the total load did not exceed the stated



Bomb Trolley, Type 'F'.



Bomb Trolley, Type 'F', with 8,000 lb. Bomb.



Detail of Bearer Attachments.

maximum. Type 'D' was soon similarly adapted to be capable of carrying the following combinations of missiles.[1]

(*a*) One 4,000 lb. bomb.
(*b*) Two 2,000 lb. A.P. bombs.
(*c*) Two 2,000 lb. H.C. bombs.
(*d*) Two 1,900 lb. G.P. bombs.
(*e*) Two 1,500 lb. Mines A, Marks I and IV.
(*f*) Two 1,000 lb. G.P. bombs.
(*g*) Two 1,000 lb. Mines A, Mark V.

It was also stated that accommodation would be extended for type 'D' to carry smoke curtain installation (S.C.I.) apparatus of not less than 1,000 lb. weight. The trolleys, apart from the incorporation of minor modifications and production of new 'Marks' from time to time, remained virtually the same until the end of the war.[2]

Suspended type winch for universal carriers

Previous to July 1931, bombs had been loaded on to the carriers by 'man handling', but, as the later design of aircraft precluded this method, a winch was designed which was suspended from the carrier or from strong points in the wings. The early design was manufactured for use with the universal series of carriers and trials showed it to be satisfactory: both the 250 lb. and 500 lb. series of bombs were loaded easily on to carriers mounted in accessible positions on the wings or under the fuselage, but was not suitable for loading internally fitted carriers where there was but little clearance between the bomb and aircraft structure. In October a free-wheel and brake attachment was incorporated and the name changed to Universal Bomb-Loading Hoist. By April 1932, the hoist was adapted for use with skeleton tubular carriers and after successful trials at an Armament Training Camp was introduced into the service in January 1933.

Hoist for torpedoes

Difficulties had been experienced in loading torpedos on to aircraft on catapults owing to the height to which the torpedo was required to be lifted from the deck. The instability of the high lift trolley when a torpedo was fully raised constituted a grave danger both to the torpedo and personnel. The torpedo section at R.A.F. Station, Gosport, were given instructions in January 1937 to investigate the possibility of loading, using hand-operated winches.

Preliminary tests were carried out using four standard loading hoists in two pairs, but when using two hoists—the normal method for bomb loading—it was found that the manual effort required was too great. A heavier pattern was designed but this was found to be inadequate and insufficiently robust. The system developed was based on the principle of a manually operated light winch mounted on a frame, one end of which was readily attachable to a special fitting on the torpedo carrier. The cable from the winch drum passed over a pulley at the upper end of the frame, then down to the lifting strop. Two winches were required, one each side of the carrier.[3]

Drawings for a modified winch were prepared by Gosport, and two were manufactured. A feature of this type was that the lower end of the frame was adjustable by means of a telescopic arrangement, and rested on the ground.

[1] A.M. File C.S. 9766/1.
[2] *See* Appendix No. 18.
[3] A.M. File S. 40055.

A stirrup was fitted at the lower end to accommodate the operator's foot and was intended to add to the rigidity of the device when in use. In the initial stages of the trial some difficulty was experienced in securing the carrying strops after the torpedo had been hoisted into position, owing to the fact that these came approximately on the centre of gravity of the torpedo and consequently fouled the lifting strop. This was overcome by producing a special lifting strop which permitted the suspension sling to be put into position without difficulty.

Adjustment of the torpedo in the fore and aft line, so that the locating lug would register with the inertia plate, was affected by positioning the lifting strop on the torpedo, whilst it was found that the torpedo could be rolled to allow the inertia plate to register by operating one or other of the winches. As a result of the trial it was recommended, in May 1939, that a quantity of winches be made for service trial, after the incorporation of minor modifications.[1]

Bomb winch for use with internally stowed bombs

When the Air Staff laid down the requirement for a standard bomb carrier for internally stowed bombs, one of the special features to be incorporated was a means of hoisting the bomb and carrier into position into the aircraft.[2] Originally it was intended to have a small winch over each bomb station, but this was found to be impracticable and the revised requirements called for a quick attachment fitting to the carrier to accommodate the hoisting cable.

The specification for a standard winch, issued at the same time as the standard carrier specification, included the following requirements :—[3]

(*a*) The winch was to be readily detachable from the installation and capable of being placed over bomb carriers accommodated in the wings or fuselage.

(*b*) It should be compact, light and robust, and suitable for operation in a confined space such as under a navigator's or W/T operator's table.

(*c*) Provision was to be made to accommodate sufficient cable on the winding drum for a hoist of 20 feet.

(*d*) A safety factor of 5 was to be provided when loaded with a 500 lb. bomb and carrier.

(*e*) A safety mechanism was to be incorporated to prevent accidental run back of the load.

(*f*) Provision was to be made on the winch for the attachment of an electric motor as an alternative to the manually operated winching handle.

(*g*) A clutch was also required to enable the cable to be quickly unwound from the drum prior to hoisting up the carriers.

(*h*) The gear ratio was to be such that one man could operate the winch and hoist a 500 lb. bomb as rapidly as possible without undue fatigue.

The prototype winches were ready for demonstration in June 1938, and at a meeting held towards the end of the month it was agreed that the winch designed by Messrs. A. V. Roe was satisfactory provided that it could be re-designed to

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[1] A.M. File S. 40055/2.
[2] *See* Appendix No. 17, para. IV (iii).
[3] A.M. File S. 43278.

accommodate 20 feet of cable and also to make it suitable for electrical operation on a 24-volt supply. Several points on the Avro winch still required attention in March 1939, and at a meeting held at the Royal Aircraft Establishment (R.A.E.) it was agreed to use the winch designed by Messrs. Handley Page as an alternative to the Avro type.[1]

Power hoisting for bomb winches

A demonstration of bomb loading by means of the Handley Page bomb winch operated by electric motor was held at the Royal Aircraft Establishment (R.A.E.) in July 1939. A 500 lb. bomb was loaded on to an aircraft manually in 3¾ minutes. An electric motor was attached to the winch, an operation taking 15 seconds, and the bomb could then be loaded in 35 seconds. At this demonstration it was found that a motor reversing switch was required to lower the bomb by electric motor. In March 1940, the Director of Armament Development (D.Arm.D.) asked the R.A.E. to investigate the most suitable type of motor for use with the 500 lb. and 2,000 lb. bomb winches.

Development proceeded at a very slow pace, and, in July 1941, Bomber Command asked for urgent action to supply the electrified winches for use in the new type aircraft—Stirling, Manchester and Halifax. A prototype motor, suitable for use with the 500 lb., 2,000 lb. and 4,000 lb. winches, was manufactured, and tests carried out at the R.A.E. were completed in February 1942. The drive from the motor was transmitted to the geared shaft of the winch through a worm and wheel reduction gear. The combined motor and reduction gear was designed to form a portable unit being capable of easy attachment and quick locking to the three studs provided on the winch cover. In one of the loading trials carried out, an 8,000 lb. bomb was loaded into a Lancaster aircraft by means of two 4,000 lb. bomb winches. Manual operation took 40 minutes and only 7 minutes by electric motor. Manual operation was extremely laborious due to the poor accessibility of the front winch.

A contract for 3,600 motors and reduction gear was placed in November 1942, and in August 1943 the equipment was submitted for introduction into the service.[2] Considerable difficulty was experienced in obtaining the tools and materials for manufacture of the equipment. The design of the gear box had to be changed to replace certain ball bearings which were unobtainable, and a further prototype had to be tested in order to prove the new design.

In view of the delay that had occurred in the production of the electric drive, two other methods were evolved by Bomber Command. One method employed a relatively simple two-speed attachment for hand operation, and was stated to afford a saving of 35 per cent. bombing up time. The second, which was demonstrated at Dunholme Lodge in October 1943, utilised standard equipment and provided hydraulic drive in which the rate of bomb lifting could be varied at will showing the maximum lifting speed to be much greater than when using the electric drive unit. In view of the efficiency of the hydraulic drive unit, the contract for the electric units was reduced to 1,000, and the manufacture of a number of hydraulic drives was put in hand.[3]

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[1] A.M. File S. 43278/2.
[2] A.M. File C.S. 18049.
[3] A.M. File C.S. 18097.

The outstanding advantage of the electrical system lay in its lightness and extreme mobility. The hydraulic attachment required a large hydraulic servicing trolley; but to fulfil the Air Staff requirement for power hoisting, the hydraulic equipment was introduced into the service in March 1944.

Flare chutes

Reconnaissance flares and similar types of pyrotechnics had been carried externally on bomb carriers up to 1936, when due to the changing rôle of aircraft employment it became a requirement to be able to launch the pyrotechnics from inside the aircraft. Early types of launching chutes consisted of a tube fitted to the floor or side of the aircraft structure, the pyrotechnics being released through this tube after being prepared for launching by the bomb aimer or air gunner.

The first chutes of this type were manufactured early in 1936, and were satisfactory in air trials carried out later in the same year. Little progress was made in design for the next four years, and the first prototype Lancaster aircraft was fitted with this early type of chute. The design was such that the top portion was removable, being stowed in the aircraft until required for use, and all were circular in cross-section.

Development of multi-cell launching chutes

Towards the end of 1941, Bomber Command had designed a launching chute having three compartments in which three pyrotechnics could be loaded and released as required—if necessary in quick succession. This design was closely followed by a six-cell chute designed by Messrs. A. V. Roe, which consisted of two front side by side square cells with two pairs of slightly smaller cells in line to the rear of the large cells. The two rear compartments were protected by armour plate and were intended for use of photo flashes. Release was accomplished by means of electro-magnetic release units.

A demonstration with the chute mounted in a temporary stand was held in March 1942.[1] The equipment was satisfactory and after minor modifications was tried in the air in June. In order that the chute could be conveniently fitted to other aircraft the designers were asked to prepare drawings of the multi-cell chute as a combination of two three-cell chutes; each group of cells was to be capable of use as an independent chute for use in installations where there was insufficient room for the six-cell unit. This design was known as the Tricell Launching Chute, and was introduced into the service in 1942.

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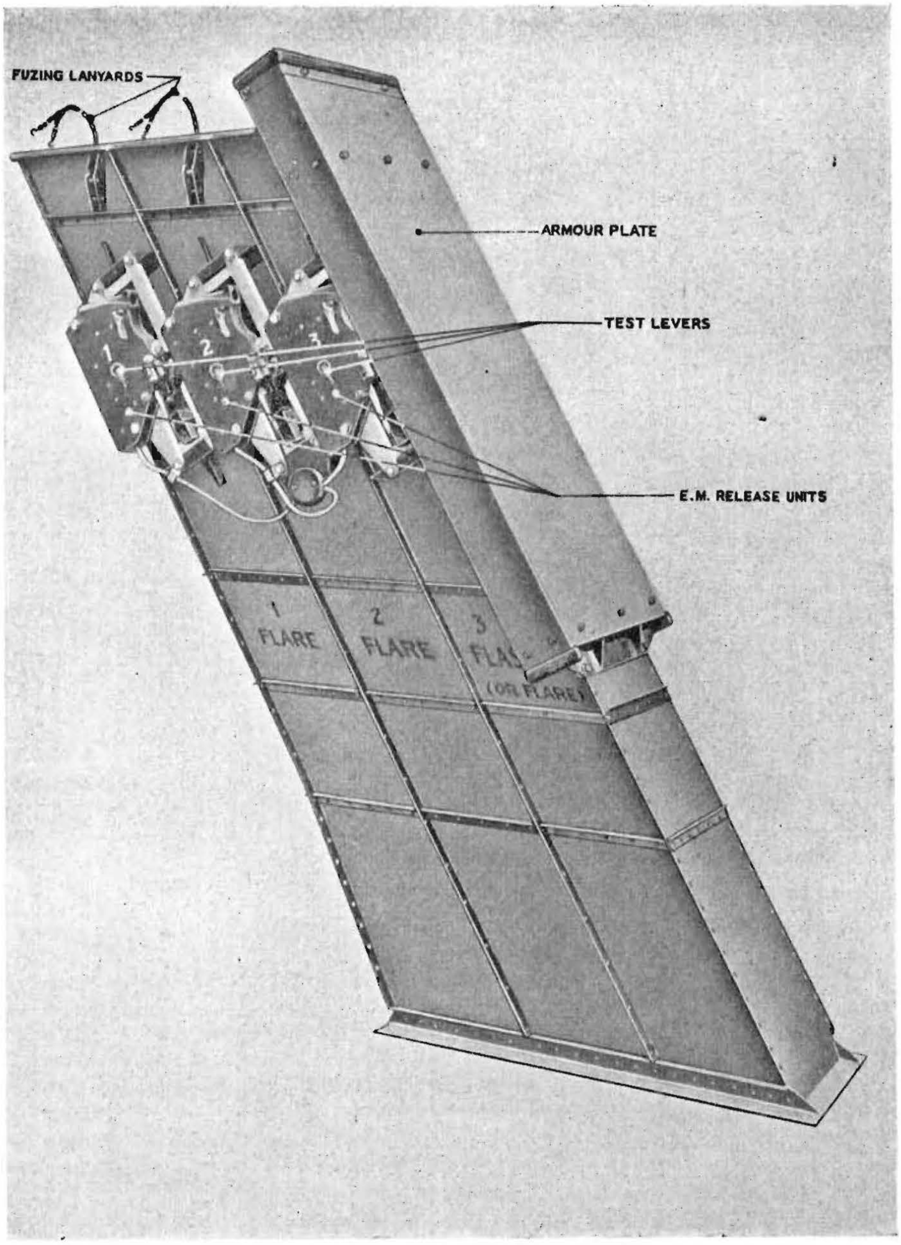
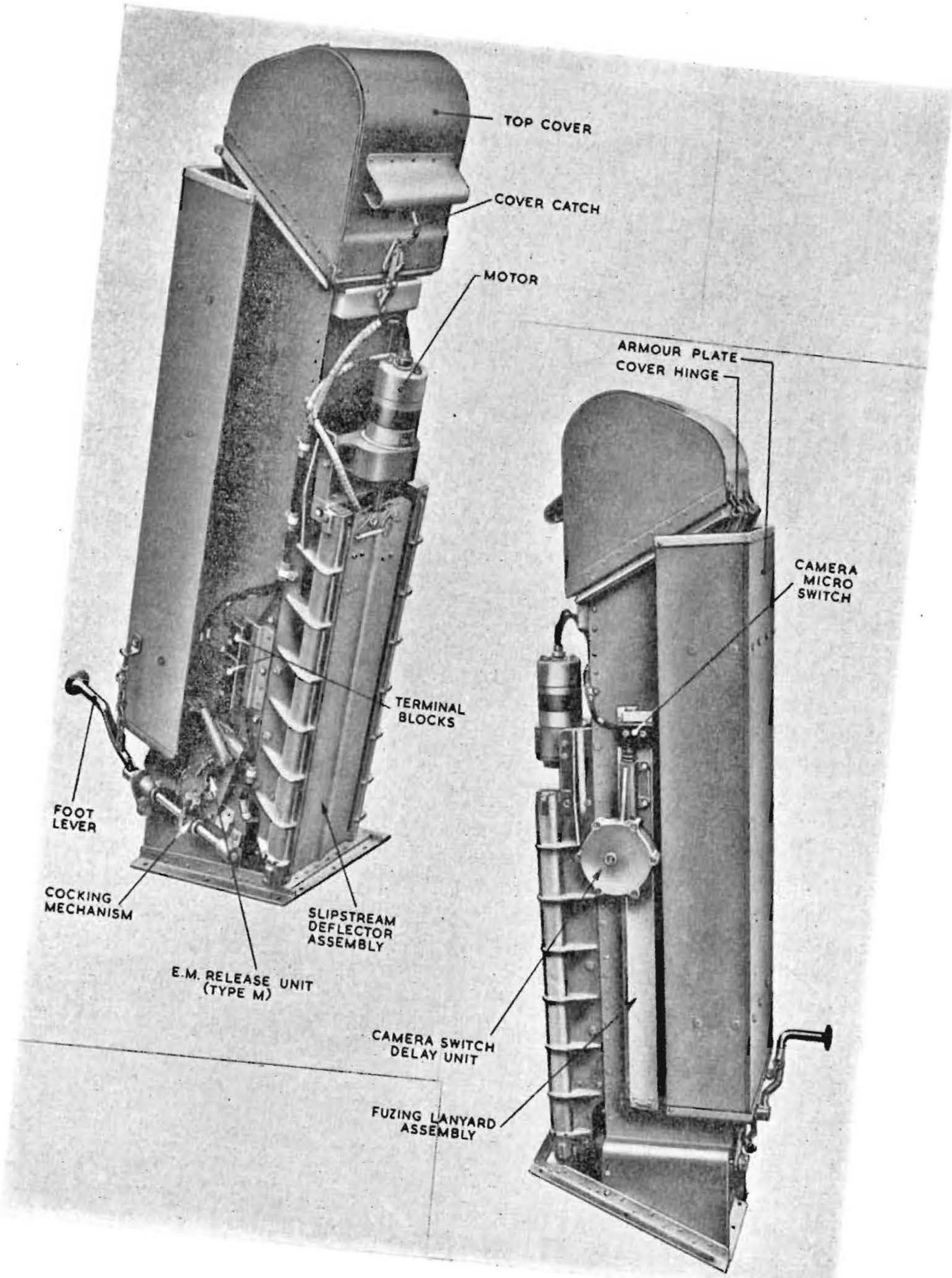
[1] A.M. File S. 40733/3.



TRI-CELL LAUNCHING CHUTE. MARK I



Launching Chute. Mark VII

APPENDIX 1

PROCEDURE LEADING UP TO THE APPROVAL OF DESIGNS OF 'LIVE STORES' SUCH AS BOMBS, BOMB COMPONENTS, PYROTECHNICS, ETC., AND THEIR INTRODUCTION INTO THE SERVICE, 1921–1939

(A) Approval of designs

In the years immediately following the 1914–18 War, no definite forward policy in the design of bombs, etc., was possible until 1921, as the main consideration until then had been the quickest way of reducing the R.A.F. to a peace-time footing. During this period too there had been no Armament Officer on the Air Staff, and requirements for new designs began to be formulated in various ways, *e.g.* the Naval Ordnance Department, Admiralty, put forward proposals for a design of Armour-Piercing Bomb to the Ordnance Committee and to the Deputy-Director of Research (Armament), Air Ministry, as the Royal Navy were interested in this from both the bomb design and the ship design points of view. The Deputy-Director of Research (Armament)—(D.D.R. (Arm.)—during the same period also worked out a programme of possible requirements, and these were eventually put forward to the Ordnance Committee after discussion with the Air Staff. It was not until some years after 1921 that the initiative in framing bomb policy came from the Air Staff.

When detail requirements for a new bomb or other store were finally agreed to by the Air Staff, D.D.R. (Arm.) took action to have the necessary designs prepared. This was done in one of the two following ways :—

(1) A preliminary sketch was prepared in the small Armament Drawing Office at the Air Ministry, and this was forwarded to the Design Department, Woolwich Arsenal, with a request for working drawings to be prepared, suitable for covering experimental manufacture.

(2) When the requirements were simple enough to be explained entirely by a written minute, they were forwarded without any preliminary sketch to the Design Department at Woolwich, either direct or through the Ordnance Committee, for the preparation of working drawings.

After these drawings had been criticised by D.D.R. (Arm.), and therefore probably amended at least once, experimental orders were placed for a small number of bombs, etc., either at the Royal Ordnance Factories, Woolwich Arsenal, or with one or more private firms. (*See* details later about the ordering of experimental stores, under (B).) After the bombs or other stores had been completed, they were subjected to various trials, tests, etc. ; and if the results of the latter were considered satisfactory, the Superintendent of Design, Woolwich Arsenal, was requested to prepare complete designs for 'approval,' which were based on the previous experimental drawings. If the trials or tests were not satisfactory, the drawings had to be modified after discussion, and a further number of experimental stores ordered to the modified drawings for trial. There was frequently a marked difference between test performance of stores at the final experimental test and that of the same stores at the 'proof' of the first Production Order.

For many years after the 1914–18 War, the procedure for obtaining 'approval' of designs was rather a complicated one for several reasons, as follows, which were partly caused by the lack of R.A.F. independence in these matters :—

(1) As there was no Armament Inspection Department at the Air Ministry until 1931, inspection of R.A.F. 'live' stores to 'approved' designs was done by Chief Inspector of Armaments (C.I.A.), Woolwich Arsenal, which was a War Office department under the Direction of Artillery, and any Air Ministry 'approval' would not have been recognised by that department, *i.e.* C.I.A., but only a War Office 'approval.' In a much lesser degree, inspection was done by the Inspector of Naval Ordnance (I.N.O.), Woolwich Arsenal, if the stores were to be carried in H.M. ships. (In the latter contingency, the Admiralty would not accept C.I.A.s inspection.) The I.N.O. at Woolwich was an Admiralty Department

under the Chief Inspector of Naval Ordnance (C.I.N.O.), who, apart from his Inspection Duties, was also an adviser to the Director of Naval Ordnance.

(2) The C.I.A. at Woolwich held the 'sealed' drawings and 'negatives' with all the attendant records, and also the bulk supply of specifications. This was a great convenience, as the Air Ministry had no similar department at that time conversant with live stores.[1] C.I.A. was also responsible for making all modifications to the sealed drawing which indicated each modification as it was 'approved.'

(3) R.A.F. bombs, etc., for many years continued to be stored in Army Depots, both at home and overseas.

(4) Following on (1), (2) and (3), C.I.A. would not seal any design of store, either Army or R.A.F., which had not been approved by the Director of Artillery ; nor would he inspect any stores on a production order which had not been made to a design approved by the Director of Artillery. In addition, R.A.F. live stores were not allowed in Army depots, magazines, etc., unless the designs to which they were made had been approved by the Director of Artillery. In all this, the Director of Artillery (D. of A.) used C.I.A. as his adviser, and would practically always approve anything recommended by him.

(5) If R.A.F. live stores were liable to be carried in H.M. ships, the designs had first to be concurred in by the Director of Naval Ordnance (D.N.O.) before approval could be given. At first this was taken only to apply to stores which would be used by the Fleet Air Arm ; but it was soon realized that the ruling would have to be extended to cover practically all live stores, as the Royal Navy might be called upon to transport R.A.F. stores at sea in an emergency, and might also want to carry in Aircraft Carriers bombs, etc., for use in combined operations, etc., which had been designed in peace-time entirely for R.A.F. use. The arrangement was therefore made that all designs of live stores of this type should be submitted to D.N.O. for concurrence before being approved, except for a very few articles which could only be used on R.A.F. Home stations, and designs of these were stamped 'Not to be issued to H.M. ships or R.N. depots.' Certain R.A.F. stores, such as Incendiary and Practice Bombs, could only be carried in H.M. ships not below decks, and these were labelled accordingly.

Before approval by D. of A. could be obtained therefore, the following departments had to be brought into complete agreement ; and this generally required patience mixed with firmness over a long period :—

D.D.R. (Arm.), Air Ministry.
D.N.O., and C.I.N.O., Admiralty.
D. of A., War Office.
C.I.A., Woolwich Arsenal.
Superintendent of Design (S. of D.), Woolwich Arsenal.

In addition, the Ordnance Committee at Woolwich acted as general advisers and as a liaison body, and frequently made recommendations for approvals ; and the Chief Superintendent, Research Department (C.S.R.D.) at Woolwich was nearly always asked to criticize any design from the purely explosive or filling point of view, although this was generally done before the designs were completed.

In general, therefore, the procedure for obtaining approval of designs by D. of A., after they had been prepared by S. of D., was as follows :—

(1) S. of D. forwarded designs to D.D.R. (Arm.), through C.I.A. instead of to him direct. This saved transit, as both S. of D. and C.I.A. were in the Arsenal ; and also D.D.R. (Arm.) was able to receive C.I.A.s criticisms with the designs themselves and consider them both together.

[1] A 'negative' is a tracing on transparent cloth, from which prints are taken of the design. A 'sealed' drawing is the master print on linen-backed white paper which has a seal placed on it after the design has been 'approved.'

(2) D.D.R. (Arm.) might or might not agree with the designs and/or C.I.A.s remarks on them ; and in general it was found quickest in the long run for D.D.R. (Arm's) representative to go to Woolwich and have consultations with both departments there at the same time.[1]

(3) Agreement having been reached so far, the designs, thus amended, were then forwarded to C.I.N.O. with a request ' to obtain D.N.O.s concurrence if all clear.' C.I.N.O. frequently made criticisms from inspection, safety and design standpoints ; and even if D.D.R. (Arm.) agreed with them, it was necessary for C.I.A. to accept them also before the next step could be taken. This very often meant another visit to Woolwich to straighten things out. C.I.N.O. could not be included in the agreement referred to in footnote at the end of para. (2) above, as his department was in London, not at Woolwich.

(4) Further agreement having been reached, D.N.O.s concurrence would be given.[2]

(5) The designs were forwarded for formal approval to the D. of A., who, seeing from the correspondence that agreement had been reached, would complete the round game by a quick signature.

When the design of any store was approved by D. of A., C.I.A. automatically made arrangements for details of the approval, and its circumstances, to be included in the War Office serial publication entitled ' List of Changes in War Material,' as this included R.A.F. stores in those days as well as Army ones. The individual items were known as L. of C., No. so-and-so, and C.I.A. circulated a copy of the subject matter of these L. of C.s to D.D.R. (Arm.) before publication. This subject matter was also circulated in Admiralty Fleet Orders.

In August 1928, D. of A., War Office,[3] suggested that it should no longer be necessary for him to give formal approval for sealing designs of aircraft bombs, etc., and that this approval could very well be given by the appropriate officer in the Air Ministry, who could communicate it to C.I.A. direct. D. of A. further stated that C.I.A. would act on his behalf as regards safety in storage, transport, handling, etc. A.D. (R.D. Arm.) (Assistant-Director of Research Development Armament), formerly D.D.R. (Arm.), agreed at once to this in principle and made arrangements accordingly with C.I.A. Thus, after many years, one further saving in the game of passing papers was made.

After A.D. (R.D. Arm.) had become the approving authority, C.I.A. forwarded to him for signature all specifications of live stores of this type which he had approved. C.I.A. still retained the sealed drawings, the negatives and the bulk supply of specifications.

When approval had been given to any design, and when it was quite clear that stores to that design would be ordered for use in the service, A.D. (R.D. Arm.) gave all details and technical data to the Director of Equipment (D. of E.), Air Ministry. D. of E. then prepared an Air Ministry Order (N) introducing the store into the service, the intention of this being to supersede the ' List of Changes in War Material,' referred to above. Based on this, Research Technical Publications (R.T.P.), Air Ministry, prepared a chapter with illustrations and/or diagrams for the Armament Manual, originally Air Publication No. A.P. 1243.

(B) Experimental orders

During the 1914–18 War, and for some months afterwards the Royal Ordnance Factories at Wolwich would start experimental work on any stores on receipt of a minute from the Admiralty, War Office, or Air Ministry, without demanding any Requisition or Extract beforehand ; and it was not necessary for the ordering

[1] Later, it was realized that time could be saved if C.I.A. and S. of D. reached agreement first, before the latter forwarded the designs to D.D.R. (Arm.), and this was therefore done.

[2] D.N.O. would nearly always give his concurrence on C.I.N.O.s recommendation ; and in any case C.I.N.O.s staff would have consulted with D.N.O.s staff as a rule before the former's criticisms were forwarded to D.D.R. (Arm) at the earlier stage.

[3] War Office File 70/Bombs/197.

authority (*e.g.* Director of Aircraft Armament, Air Ministry, etc.), to obtain financial sanction before sending the minute. This had the great advantage of the work being started almost simultaneously with the decision to do it ; and, in many cases, orders were given verbally and confirmed afterwards in writing. The disadvantage was the difficulty of keeping any control over the financial liability incurred, costing, etc.

After the 1914–18 War, with its inevitable loosening of financial control, it was decided by the War Office, after the winding up of the Ministry of Munitions, to run the Royal Ordnance Factories (R.O.F.) at Woolwich 'on business lines.' New systems were introduced, whereby orders could no longer by given verbally ; and not even urgent experimental work could be started without a Requisition or Extract. Even after the receipt of the Requisition at Woolwich, it was several days, and frequently weeks, before anything would be done in the Factories, owing to the elaborate method of transmitting the orders by the Administrative staff. In addition, to make progress even slower, practically no stocks of materials were allowed to be held by R.O.F., so that for each experimental order small quantities of materials had first to be ordered from outside. In some instances, tenders were even put out for this, to make sure that the materials were bought at as low a price as possible, and this caused still more delay. In view of subsequent events, it may now seem difficult to believe that such a system could have been allowed to continue, but the War Office policy then, and for 10 to 12 years afterwards, as dictated by the Cabinet, was based on the supposition :—' No major war for 10 years.' There was also for several years a great public outcry for more control of, and cutting down of, public expenditure, particularly on Armaments, as exemplified by the ' Geddes Axe.'

As however, a large part of the experimental work had to be done by the R.O.F. rather than by Trade firms, owing firstly, to their great experience, at that time in this type of work, secondly because of the useful liaison and advisory work of the Ordnance Committee in the Arsenal and thirdly because the orders were too small to interest most firms, these delays had to be accepted ; but these very delays only stressed the importance of trying to save time in the placing of the orders at the Air Ministry end.

Now at about the period 1920–21, the only type of Requisition authorised in the A.M.S.R. department for experimental work was that known as a ' Technical Requisitions ' ; and the procedure laid down for using this, which did not make for rapid execution, was as follows :—

D.D.R. (Arm.), or any of the other Deputy-Directorates under the Director of Technical Development (D.T.D.), completed the Requisition, and then forwarded it with a covering minute to D.T.D. for approval and signature, if concurred in, and to the appropriate Finance Branch for financial approval. The file, specially opened for the purpose, was then sent back to D.D.R. (Arm.), who forwarded it to the Director of Equipment (D. of E.) with the necessary drawings for contract action. (Sometimes the drawings had to follow later.) D. of E. then minuted the file to Director of Contracts (D. of C.) for action. Unless the Deputy-Director in D.T.D. concerned could give some very good reason why the experimental contract should be placed with a certain firm or firms (or with the R.O.F. at Woolwich), the D. of C. called for tenders from several firms, and placed the order with the firm submitted the lowest price, after sending the file first to D.D.R. (Arm.) or other Deputy-Director, to see the completed tender forms. It would thus be several weeks after the completion of the original Requisition before any order could be placed.

It was not possible for D.D.R. (Arm.) to modify this procedure, or type of requisition, so far as private firms were concerned, as it was common to all the other experimental departments as well, *i.e.* it covered Aircraft, Engines and all accessories as well as Armament ; but it seemed possible that it might be short-circuited in some way for work done at R.O.F., Woolwich, on bombs and other live stores.

D.D.R. (Arm.) therefore devised the following scheme in conjunction with the Woolwich departments concerned :—A simplified form of Requisition was produced, with the suffix R.A.2, etc. (short for R.Arm.2, the section in the Deputy-Directorate dealing with bombs, etc.). On completion of the Requisition, it was taken by hand by the clerk in the section concerned to the Finance Branch for financial concurrence, which was given on a typed Form accompanying the Requisition, a rough estimate of the amount involved being included on the typed Form.[1] Copies of the Requisitions were then forwarded immediately by D.D.R. (Arm. to all the Woolwich departments concerned, *i.e.* Ordnance Factories, Design Department, Inspection Department and Ordnance Committee. In this way the requisitions were received for action 24 hours after being completed.

(C) Production orders, inspection and proof

Air Staff (Director of Operational Requirements) forwarded to the Director of Equipment (D. of E.) details of the quantities of the various types of stores required for equipping the Service squadrons and for the war reserve, and Director of Training (D. of T.) forwarded similar details of stores required for training.

Based on these requirements, D. of E. prepared sketch estimates each year about September, for approval by Parliament the following March or April. After the estimates had been approved by Parliament, requisitions to purchase could be raised against the appropriate Vote, although each requisition had to receive a separate financial approval from the responsible Air Ministry Finance Branch. Generally, supplementary estimates had, in addition, to be prepared later in the financial year, as more money than visualised initially was practically always required before the twelve months were completed, and a reshuffle of allocations within the Parliamentary grant was necessitated.

In order to place a requisition for bombs or similar stores, D. of E. filled in the appropriate requisition form based on detailed information received from the Armament section concerned, put it in a specially raised new file, and sent it to the finance branch concerned, for financial approval. On its return the file was sent to the Director of Contracts (D. of C.) for contract action. D. of C. sent out tenders to a number of firms which he knew were suitable for the particular work required, and in normal circumstances placed the order with the firm which submitted the lowest tender.[2] Copies of the contracts were checked by the appropriate armament section to ensure that the designs and specifications quoted were up to date.

There was an exception to this procedure in the case of the Royal Ordnance Factories (R.O.F.) at Woolwich (now the Ministry of Supply). By agreement with the War Office and in accordance with the policy of the Government, a proportion of the production orders had to be placed with the R.O.F. in order to keep them going; and the Chief Superintendent of Ordnance Factories (C.S.O.F.) forwarded a list to D. of E. each year giving details of the type and amount of work which could be done there. D. of E. placed an 'extract' (a particular form of contract in vogue at Woolwich) direct on the R.O.F. for this work, as D. of C. was not concerned, no tender being required. A maximum price, however, was fixed.

During manufacture, the stores were subjected to detail inspection for conformity to the design and specification, and in most cases, after completion, were also subjected to 'Proof.'[3] Whether intended for warfare or for training, completed stores were separated into 'Lots,' the number constituting a 'Lot' usually varying inversely with the productive effort involved. Thus, the number in a Lot of large bombs is much smaller than, for instance, the number in a Lot of small incendiary bombs. The percentage selected from the Lot, however, also varied in proportion, the object of 'Lotting' being to reduce to a minimum the extent of scrap resulting from failure and, therefore, rejection at Proof. A second Proof, known as 'Double Re-Proof,' was usually allowed, and in special circumstances a third re-proofing before the Lots involved were finally rejected.

Some types of Proof, for example, that consisting of dropping stores from the air at the Aircraft and Armament Experimental Establishment, were supervised by the Director of Armament Development (D.Arm.D.) and not by D.A.I. (Director of Aeronautical Inspection), the latter signing the Proof papers after they had already been certified by D.Arm.D.

[1] This should be compared with the procedure with private firms referred to above, where the cost depended on the results of the tenders.

[2] On some occasions advertisements asking for tenders were put in the Press.

[3] 'Proof' is the test of a small percentage of the completed stores under conditions simulating, as far as practicable, the way in which they would be used under Service conditions.

Proof done with the stores newly manufactured is known as 'Acceptance Proof,' but periodical examination and Proof has also to be done during the storage of live stores.

Reference has been made earlier to the frequent differences between the good performance of stores at the final experimental test which caused the design to be approved, and the poorer performance of stores made to the same design when 'Acceptance Proof' of the early production orders was done. There were many reasons for this, some of which were :—

(1) The experimental stores had been made either at Woolwich or by firms who had had a lot of experience in the type of work involved, and estimates of cost were not rigidly enforced.

(2) In production orders firms were working to a fixed price, which they had made as low as possible in order to get the work. So long as they could get the stores through Proof, nothing else mattered.

(3) Concessions were given by the Production and/or Inspection Department to the manufacturer so as to make some small features of the design more suitable for his plant and facilities. In these cases, reference was usually made to D.Arm.D. before giving agreement. Although it would appear at the time that the concessions given could not possibly affect the correct working of the store in Service use, it was frequently found out at 'Acceptance Proof' that such had been the case.

In an attempt to overcome this serious type of setback, large experimental contracts, sometimes known as Development Contracts, were placed with several firms before the designs of stores were approved, and, therefore, in advance of production orders. This gave time for some of the 'teething' troubles of production to be overcome, including troubles between Contractor and Sub-Contractor ; and it was also a means of determining whether various modifications to the design required by each individual Contractor had any adverse effect on functioning. The poor performance obtained from some of the early production orders, however, was never entirely eliminated.

At some of the larger firms' works D.A.I. kept a Resident Inspector-in-Charge, with a staff of examiners ; and with some of these firms he used the principle of 'Approved Inspection,' which meant that suitable employees of the firms were trained to do the inspection themselves, both during manufacture and on completion, including gauging. This was naturally subject to supervision by the D.A.I., including periodical checks, and did not dispense with the necessity for Proof.

For contracts placed with the R.O.F. at Woolwich D.A.I. delegated the inspection to the War Office Inspection Department there, *i.e.* Chief Inspector of Armaments (C.I.A.). The latter's organisation was very comprehensive and complete with examiners well trained in dealing with explosive stores ; and contractors for rather similar stores, for example fuzes, exploders, detonators, etc., placed by both War Office (now done through the Ministry of Supply) and Air Ministry (now through M.A.P.) would be frequently running in the same building. If stores being made in the R.O.F. were for the Fleet Air Arm, D.A.I. delegated the inspection to Inspector of Naval Ordnance, Woolwich (I.N.O. (W)).[1]

After passing inspection and proof, completed stores from Woolwich or from private firms were delivered to the appropriate Ammunition Depot (now called Maintenance Unit). Training Units demanded stores, *e.g.* Practice Bombs, direct on the ammunition depot for training purposes, up to their allotted quantity, and these were 'turned over,' *i.e.* used up over a certain period, and then further demands made on the depot. For equipping Service Squadrons with live stores for war purposes, D. of E. arranged the numbers of the various types of stores to be provided by the depot in accordance with the programme drawn up by Director of Operational Requirements. This was done as quickly as the bombs, etc., became available and so soon as the necessary bomb stores, magazines, etc., could be constructed at the R.A.F. stations concerned.

[1] For many years, D. of E. placed orders for empty bombs, etc., for the Fleet Air Arm, under Admiralty inspection, but the Admiralty arranged their own filling of the bombs. Part of the reason for the latter was that the Admiralty often used a different main filling to the Air Ministry for the same type of bomb, *e.g.* T.N.T. instead of Amatol, and the Admiralty controlled their own stocks of T.N.T.

PROCEDURE GOVERNING DEVELOPMENT AND INTRODUCTION OF EXPLOSIVE STORES, ETC., FROM 1939 TO 1945

The routine procedure detailed in the preceding pages was built up under peace conditions and with the commencement of the re-armament programme the introduction of material changes became automatically necessary.

The basic features which dictated the re-modelling of the procedure were as follows :—

(a) The scale of manufacture demanded was entirely beyond the capabilities of stereotyped production methods around which existing designs had been prepared.

(b) As the ' temper ' of war developed, the continual trend of changing fashions in air warfare resulted in continual additions to operational requirements.

(c) Development progress had to be considered in terms of ' weeks ' rather than of ' years ' and the resultant pressure on design facilities made it imperative to co-opt the services of trade establishments both from the points of view of making efficient employment of available capacities and to exploring adoption of techniques not previously applied to armament manufacture.

(d) The transfer of development to the Ministry of Aircraft Production and the consequent continuous liaison with Production Directorates. Under these conditions the contrasting claims of efficiency and mass production had necessarily to be compromised.

Under these changed conditions it is opportune to review the wartime machinery from the followng aspects :—

(i) Development history of main H.E. weapons during the war period.

(ii) The effect of war conditions on general development procedure.

Regarding (i) above the main development progress, stated under appropriate sub-headings is summarised below.

G.P. Bombs No. 1. It was anticipated that these bombs (developed during pre-war period) would form the basic bombing weapon under war conditions. Designed to be manufactured as forgings and thus to offer the maximum efficiency for resistance impacts, it was found even under peace manufacture that allocation of forging facilities was inadequate and manufacture as steel castings with a few specialist firms was permitted and reasonable efficiency was obtained. With the building up of war production programme, however, the resultant introduction of inexperienced foundry concerns led to marked deterioration in the structural efficiency obtained and the limitations of forging facilities made it essential to allocate the bulk of such capacity to piercing weapons (*i.e.* A.P. and S.A.P. types) with the result that intensive exploration of case manufacture became compulsory.

With a view to obtaining the maximum values from this source of supply the Steel Casting Control undertook the formation of a Committee to co-ordinate experience and technique of 40 to 50 foundries concerned. Competitive co-operation was encouraged and extensive research into chemical analysis of grain control techniques carried out, with the result that output was improved to a standard which compared as closely as possible with forged construction. The standard reached was ultimately extended to the MC range of bombs (*see* below).

H.C. Bombs. With the concentration of bombing on built-up areas in this country the advantage of blast weapons from the aspect of general bombing efficiency became apparent and requirements for bombs of this type were stated. This development called for the use of manufacturing methods not previously employed for weapon design (except in the case of the SN bomb in the 1914/18 war). After the preparation of basic designs indicating stowage and detailing limitations the detail methods of construction were vested in various firms specialising in heavy engineering fabrication. The co-operation received from such sources permitted the introduction of this class of weapon into the Service within a very limited period and the co-operation continued throughout the range from 2,000 lb. to 12,000 lb. weapons. Considerable proportion of the Service production was vested in the individual concerns who developed the constructive methods.

M.C. Bomb. Concurrently with the development of blast weapons referred to above, the advantages of increased charge capacities for the attack of general industrial targets became apparent and a requirement was stated for bombs on similar lines to the German SC bomb. The 500 lb. size was the first instituted in this range and the design, as prepared, anticipated building up capacity for solid drawn manufacture as used to a great extent in both the German and American versions of similar weapons.

Available capacity for such manufacture was, however, almost negligible and adoption of other production methods, became essential to meet the mass requirements. The following alternatives were explored :—

(*a*) Fabrication using general engineering facilities.

(*b*) Steel castings using the co-operative machinery already set up for the GP bombs.

As regards (*a*) the development was mainly centred around tube construction interests and developed tests against resistant targets gave encouraging results. Adoption of this type for Service use showed, however, that the efficient welding technique developed by the parent contractor could not be consistently applied by all sources of manufacture which were available. A Contractors' Committee, representing all firms employed on this type, was formed on the lines of that appointed for steel castings and this Committee gave valuable service in correlating the welding techniques employed.

As regards (*b*) the adjustment of available technique to light wall castings formed the main problem of development, but with the continued collaboration of the Steel Casting Committee effective results were obtained and in a comparatively short time the cast steel version became a mass production effort. The standard obtained remained generally satisfactory and the stability of type was ensured by the establishment of drop hammer test equipment. This equipment was used primarily to ensure a maximum standard for all supplies, being continued during manufacture to maintain that standard.

The 1,000 lb. version of this bomb was developed on a steel casting basis only, using the machinery then existing. In view of experience already available this particular application did not present any specific problems.

The 4,000 lb. version of this bomb presented a more definite development investigation and, in collaboration with heavy engineering interests, a design to take advantage of spinning and special welding techniques was evolved. The strength limitations of fabrication were again experienced in this instance and owing to enforced limitations to low level use the bomb was not generally adopted.

At a later stage of the war a limited forging capacity (ex 500 lb. S.A.P. and 2,000 lb. A.P. bombs) became available and a fully forged version of the 500 lb. and 1,000 lb. bombs was developed in conjunction with the individual facilities of the capacity concerned. These bombs were mainly segregated for use as special ship attack weapons.

General. There were many 'special' weapons which were specifically developed within the planned limitations of individual firms. Further, in many instances actual development of associated stores such as fuzes and detonators has been vested in trade establishments with very satisfactory results. The co-operative assistance obtained in this way was a valuable contribution to expeditious development clearance.

Regarding (ii) above, the changed conditions of wartime development necessitated many diversions from the machinery set up in the pre-war period and these are briefly summarised in the following notes.

Experimental manufacture. All development manufacture was based on a quantity basis which justified the employment of production methods. This arrangement facilitated progress in two ways ; firstly by overcoming the inevitable delays which arise in obtaining comparable firms in both prototype and initial production supplies, and secondly that sufficient stores would become available for fully representative Service trials to run concurrently. This arrangement was, of course, mainly permissible by the unlimited purse of war emergency and this factor would be to a great extent responsible for the expeditious introduction of stores into the Service.

The number of stores ordered under a development contract was normally determined by desirability for production tooling rather than by anticipated trial requirements. The surplus stores available when adoption was approved were transferred for Service use pending normal production.

Design procedure. Owing to the excessive load placed on design facilities by extensive war requirements the procedure set out in earlier chapters became, to a large extent, inoperative. Whilst every endeavour has been made to correlate official design records with Service adoption, the urgency of production made it imperative to originate production to semi-official drawings prepared either within M.A.P. or by contractors. In certain cases full scale production was built up on such drawings, formal action to complete sealed designs being taken concurrently, all resultant production details being embodied to form a complete record of bulk manufacture.

Under these circumstances the formal sealing of designs became subsidiary to the development effort although co-ordination with the Ordnance Board was maintained. Whilst the machinery set up to guide approval was respected in general principles, the detail method of application was dependent on prevailing circumstances.

Air and Naval Staff approval for production. One aspect which has been applied without relaxation during the war period is that of obtaining the clear approval of Staffs concerned before initiating production. The routine to accomplish this, although determined long before the war, was not strictly followed until rapid introduction of new stores began. The actual procedure followed during the war years is outlined in the following paragraph.

When D.Arm.R.D. was satisfied with development and was prepared to recommend adoption, a special file was raised to cover ' Introduction into the Service.' Copies of all relevant development and Service trial reports were included in this file and a summarised pro forma of all details. The formal recommendation for approval was thus made to A.C.A.S. through C.R.D. in an explanatory minute dealing with all aspects. When A.C.A.S. (or Naval Staff) approval was given the file was passed direct to D.G.E. (Equipment) who, on the authority of the approval, issued instructions for production.

Elimination of proof tests. With the increased pressure placed on normal acceptance proof tests by the increased war production, the general application of the test for all main H.E. and practice weapons was considerably relaxed and to a certain extent discontinued. The test with H.E. filled bombs completely over-loaded establishments required to concentrate on development trials and the fact that such routine tests had been made for long periods without failures which could be directly attributable to bomb filling was accepted as justification for discontinuance. Proof testing of such subsidiary stores as detonators and fuzes and for pyrotechnic stores, the efficiency of which is mainly dependent on craftsmanship and individual effort, has been continued without relaxation.

Provisioning procedure. The machinery detailed in earlier chapters as covering these aspects was completely modified as a result of war organisation.

Consequent on an approval of stores for production the Equipment Directorate authorised manufacturing arrangements to proceed concurrently with action with Finance Branches.

Development Branches in the main were made responsible for notifying the Production Directorate (D.Arm.P.) of all manufacturing details and thereafter technical production problems were dealt with between the development and production organisations. In the direct liaison thus set up the interests of the inspection aspect were given full consideration and subsequent to the placing of actual contracts, problems of concessions and relaxations of conditions were only reviewed at the instigation of the latter Department.

Custody of sealed drawings. The machinery for custody of designs and specifications was completely reviewed at the outbreak of war, in that all documents previously held by C.I.A. came under the direct control of D.G.A.I. (D.D.I.Arm.). The documents have since been held in the custody of a special branch known as A.I.D./E.A.U. (Explosives and Ammunition Unit). The routine and responsibilities of ' sealing ' as originally performed by C.I.A. has since been continued by that Unit.

Publications. The procedure for advising the Services of the introduction of new stores has also been essentially reviewed owing to general pressure on the publications branch (R.T.P.).

During the latter period of the war a scheme of issuing Advance Instructions was initiated under the control of the Servicing and Maintenance Directorate (D.S.M.). Technical information to form the basis of these instructions, prepared in brief by the Technical Branch concerned, was supplemented as necessary by direct contact with D.S.M. personnel with the actual stores, and the promulgation of essential information was effected with the minimum delay. The Advance Instructions issued became the basis of the complete technical instruction prepared by RTP for subsequent issue in armament manuals.

APPENDIX 2

AIRCRAFT DEPTH CHARGES[1]

Early use of ship type depth charges

At the beginning of the war, no work at all had been done by this Department on an anti-submarine weapon for use from aircraft, but early in the war a better weapon than the 250 lb. A/S Bomb existing at that time was called for and trials were carried out to ascertain if the Mark VII depth charge could be dropped from aircraft with satisfactory results.

The depth charge was fitted exactly as for shipborne use, except that a suspension band was clamped round it to provide the necessary bomb-lug for attaching it to the aircraft, and a metal cap was fitted over the end of the primer tube to prevent impact with the water forcing out primer and pistol if the depth charge should strike primer first. The depth charge was fitted in the aircraft so that it would strike the water pistol last, though trials were carried out with drops pistol first to ensure that no danger would ensue if this occurred.

To reduce the air-resistance caused by carrying such large objects in external stowages, sheet metal fairings were designed by R.A.F. for fitting to the depth charges. These fairings also improved the flight in air, but as they broke off on impact with the water the underwater behaviour was the same whether fairings were fitted or not.

Development of 200 lb. aircraft depth charge

The size and weight of the Mark VII depth charge prevented its use in some types of aircraft, and a requirement arose about the middle of 1940 for an airborne anti-submarine weapon designed to be suitable for dropping from aircraft of Coastal Command and having in particular an all-up weight limit of 250 lb. To meet this, a design of depth charge was produced—known ultimately as Mark VIII—which retained the essential features of the Mark VII but was of greater length and smaller diameter. A drum type tail was included to give the weapon adequate stability in the air. Acceptance trials on the Mark VIII depth charge were carried out satisfactorily in December 1940.

In view of the long thin nature of the charge case (11·0 inches diameter by 38·0 inches long) a through primer tube was not practicable so a blind primer tube was adopted involving the insertion of the primer before the pistol. The primer was the standard Mark VII Primer with handle and stopper removed, and the threaded shank of the bung shortened ; this form was known as Mark VIII depth charge Primer.

About the same time, it was decided to fit aircraft flown from Aircraft Carriers with depth charges, and in these circumstances the then current practice of setting a depth on the pistol before the aircraft took off could not be accepted, as in the event of a crash or forced landing on the sea there was a strong probability of the depth charges being torn off and exploding on reaching their set depth.

[1] Notes compiled by the Superintendent of the Naval Mines Department, Havant.

Modification to ship depth charge pistol for aircraft use

A modification to the Mark VII pistol was therefore introduced whereby the rotation of the orifice plate was obtained through the medium of a pre-wound torsion spring. The orifice plate was retained in its ' safe ' position against the torsion of the spring by a clip which could be attached to the fuzing control unit of the aircraft through the medium of a fuzing link. When dropped ' live,' the fuzing link was retained by the aircraft, thereby causing the clip to be pulled off the pistol, the spring then being free to rotate the orifice plate to a previously determined setting : these settings were the three shallowest of the Mark VII Pistol, viz. : 50, 100 and 150 feet. The first 24 pistols—designated Mark X—were supplied to H.M.S. *Illustrious* for trial in September 1940, followed by a further 24 to H.M.S. *Furious*.

Early lack of trial facilities

To understand the situation at this stage (late 1940) it is necessary to realise that during the early part of the war, there were no trial facilities available to the Department for ascertaining the behaviour of depth charges and their components when dropped from aircraft. The only trials were carried out by the Marine Aircraft Experimental Establishment of the M.A.P. situated at Helensburgh, and consisted in dropping live charges and observing whether or not they exploded satisfactorily. On this basis, limiting heights and speeds for dropping which would give a reasonable certainty of explosion were laid down, the limits for Mark VII depth charge being 100 feet and 100 knots. No facilities were available for dropping inert filled weapons for subsequent recovery and laboratory examination, such as later were established at Weston-super-Mare.

The result was that the existence of design faults leading to unsatisfactory performance could only be ascertained on a statistical basis, and very little information could be obtained as to the cause of the failures. The difficulties were enhanced by the trial facilities being under the control of another Service and at a place remote from the Department.

Such was the position early in 1941, by which time material had been delivered to the Services in sufficient quantities for some appraisal to be made of its reliability and usefulness. By March 1941, it had become apparent that the limitations of height and speed for the Mark VII depth charge were too restrictive, and trials were carried out (on the statistical basis mentioned above) to ascertain if they could be raised. These trials led to the realisation that the force of impact dislodged the cap fitted to protect the primer, with the result that both primer and pistol were forced out. A much stronger bung was then introduced to remedy this defect.

Requirements for improved designs

By the middle of 1941, it began to be apparent that the firing depth of both Mark VII and Mark VIII depth charges was too deep for effective attack against surfaced submarines. Moreover, pressure was continually being brought to bear to increase the limit for striking velocity to permit more freedom in the method of attack. In addition, the occurrence of occasional premature detonations (referred to later) led to an intensive search for possible causes and means of eliminating them.

From this time until the autumn of 1942 was a period of intense activity in pursuing these ends, all three requirements reacting on the designs, as well as the minor day-to-day troubles inevitably associated with development.

Although the development of the weapons to meet all requirements was proceeding simultaneously, it will be convenient for historical purposes to indicate separately how each requirement was tackled.

Reduction in firing depth

To reduce the firing depth, the first and most obvious step was to fit a weaker firing spring in the pistols. This step was not very successful, and it was then thought that owing to the high entry speed there was insufficient time for the necessary volume of water to have entered the primer tube by the time the depth charge was at the firing depth, so the next step was to increase the number of water entry ports. With this pistol arrangement (Mark XIII*), firing at 30–35 feet had been achieved in April 1942.

It was apparent by this time that some more fundamental change in design was necessary to achieve the firing depth of 15–20 feet which the Staff were demanding, so experiments were put in hand to try the effect of a ' spoiler ' nose and a ' break-off ' tail. The objective was to cause the weapon to become unstable in its underwater trajectory so that, instead of travelling underwater with its axis on trajectory, it would tend to turn broadside on thereby considerably retarding its motions and also bringing the after end (containing the pistol) into contact with the cavity wall.

Small scale trials carried out at the Admiralty Research Laboratory, Teddington, by firing 1·0 inch diameter models into a glass-sided tank and photographing the resultant behaviour indicated that the idea was very promising, and full scale material for depth-of-firing trials was put in hand. The ' spoiler ' nose was obtained by reversing the existing nose plate of the depth charge so that it presented a concave instead of convex front ; the tail was made to break off on impact by securing it to its brackets with aluminium instead of steel rivets, and by halving the number of brackets. Under these conditions, it was found that the ' set-forward ' of the tail on impact was sufficient to cause the rivets to shear, the tail thus becoming detached. To convert existing Mark VIII depth charges to have the spoiler nose, a fitting was made which could be clamped on which converted their leading end into a concave surface.

The new depth charge was known as Mark XI, and trials were so successful that by July 1942, all production of aircraft depth charges was concentrated on this type. By this time, also, the use of Torpex as an H.E. filling had started, so the effectiveness of the weapon was further increased by some 50 per cent. by the use of this explosive in lieu of Amatol.

Increase in permissible striking velocity

To increase the heights and speeds of release required the ascertainment of the causes of failure if the conditions then permitted were exceeded.

Towards the end of 1941, it was apparent that the principal cause was distortion of the orifice plate seating due to inertia forces, set up on impact, thus permitting pressure to obtain access to the ' back ' side of the diaphragm and so nullify the firing pressure. As a temporary expedient, the orifice plate was removed and a plug substituted ; the resultant pistol had only one setting and no safety feature and was known as Mark XII. This pistol had only a very limited existence, but it led the way to the next step—' safety by back flooding.' Up to this time, safety—*i.e.* preventing the pistol firing on the application of pressure—had been obtained by mechanically resisting the forces set up on the firing system by the hydrostatic pressure ; it was now seen, however, that if the above-mentioned plug were made removable at will, the pistol would be " safe " in its absence since then both sides of the diaphragm would be exposed to the same pressure.

The application of this development was facilitated by a decision to limit the number of firing depths to one—the shallowest—since by this time it was realised that the likelihood of an attack being successful was very remote unless there was a visible target for the aircraft.

There was thus developed the Mark XVI pistol which was a standard pistol except for a weak firing spring (static calibration of about 22 feet of seawater), the elimination of the safety rod, and the substitution of a spring loaded valve device for the orifice plate.

Improvement in inertia-proof qualities of pistol

Further reference will be made to all the aspects of premature firing ; for the present purpose it is only necessary to say that a possible explanation of these accidents was that differential ' bounce ' of the two sleeves of the firing unit in the pistol might take place. On impact, the lower sleeve sets forward thereby completing half the firing stroke ; the upper sleeve is pressed on to the distance ring through the diaphragm. The theory required that while the lower sleeve was still set forward, the upper sleeve should rebound due to release of the energy stored in compressing the rubber of the diaphragm sufficiently to cause the pistol to fire. Many trials were carried out to ascertain exactly what movement of the sleeves did take place on impact, and in no case did the parting of the sleeves come near to the amount necessary to fire the pistol. Nevertheless, it was considered desirable to eliminate this possible cause, and the very neat solution was proposed of omitting the distance ring. This omission meant that on impact the two sleeves moved together as a unit and no parting at all could take place.

Introduction of new aircraft depth charge pistol

The stage was now set for the introduction of a pistol specifically designed for use with aircraft depth charges instead of making modifications to the pistol designed and intended for ship use. The pistol—known when approved for service as Mark XIV—had the following features :—

(i) Adequate strength to resist inertia forces due to impact without distortion.

(ii) Large internal volume to reduce back pressure and so fire shallow without further reduction in firing spring strength.

(iii) Safety by ' back-flooding.'

(iv) Inertia-proof firing mechanism of ' floating ' type.

(v) One (shallow) depth setting.

The Mark XI Depth Charge with Mark XIV and XVI pistols was accepted for service in September 1942, and except for minor alterations remained the standard combination for the rest of the war. In one small feature, the pistol designs required improvement inasmuch as the depth charges would occasionally fire when jettisoned ' safe.' This was believed to be due to the safety clip being pulled off by the fuzing link becoming entangled with the tail when the latter broke off on impact and so a small pellet, to be set forward by inertia, was incorporated in the safety clip so that it became impossible to pull the clip off, once the pellet had set forward. This modification proved a successful cure of the trouble, and was approved in January 1943, pistols incorporating it being termed Mark XIV* and XVI* respectively.

Requirement for improved safety of carrier-borne depth charges

It will be convenient to break the narrative at this point to refer to a requirement raised in January 1942, to improve the safety of carrier-borne depth charges. It was felt that any arming device which depended for its operation on the removal of an item was always liable to accidental operation, especially with carrier-borne aircraft which might crash over the side with very serious consequences to the carrier if the depth charges then exploded. The desideratum was an arming device which depended on the addition of something, and the proposal was made to meet this by storing the energy to carry out the arming in the aircraft and not in the weapon, so that if the weapon was torn away the arming device became dissociated from its source of energy and the pistol therefore could not possibly fire.

The detail of the method was to secure the safety clip to the pistol with a shear pin, and to provide a small explosive charge on the pistol to shear the pin and remove the clip. This explosive charge was to be electrically fired from a battery on the aircraft, the circuit being under the control of the pilot so that—unless the pilot had made his switch—the depth charge would remain safe in all circumstances. The device was called the Explosive Safety Clip and could be fitted to Mark XIV and Mark XVI pistols ; it involved modification to the wiring of bomb carriers, and the provision of a socket on the latter to which the lead from the Clip could be plugged. Acceptance trials in November 1942, were successful and the device was released for service use. Unfortunately, it did not prove to be entirely reliable though the exact cause of failure has not been finally ascertained.

It was further discredited when in one instance explosions followed after an aircraft had crashed into the sea, a possible explanation being that the circuits had been completed either by a sea-water path or by the pilot, in trying to escape from the cockpit. Its use was finally discontinued in April 1945, when extended trials with air-arming (see later) had proved this latter to provide adequate safety for carrier-borne depth charges.

Introduction of horizontal fuzing

To resume the main narrative, the next requirement was to arrange for 'horizontal fuzing.' The entry of the U.S.A. into the war required that, as far as possible, weapons should be interchangeable between the aircraft of the two countries, especially as American types of aircraft were being used increasingly by the R.A.F. and F.A.A., but there was a difficulty with airborne weapons since the Americans employed horizontal fuzing as compared with the British vertical fuzing. The decision to standardise horizontal fuzing for both countries required that the depth charge be brought into line, and it was convenient to do this by utilising air-arming—a technique the adoption of which had been pressed for some time by M.A.P. on the grounds of improved safety. Air-arming requires the independent flight of the weapon through the air to arm it, and this is usually achieved by fitting an air vane to nose or tail which—by its rotation in the air stream—causes arming.

Difficulties had also been experienced in handling depth charges with tails since the tails with their weak aluminium rivets were liable to break off during handling. A satisfactory design of break-off tail of the fin-and-drum type had already been developed by M.A.P. and it was consequently decided to adopt this type, which also lent itself to the air-arming technique.

An alteration to the pistol was required to cause the valve to close by rotation instead of under spring action ; and this was a simple matter, only involving a new cover to take a screwed valve spindle. Mark XIV pistols modified thus were termed Mark XX, and the new tail was Tail Mark IV. Minor modifications to make these more suitable for Fleet Air Arm use caused them to become Pistol Mark XX* and Tail Mark IV*, and these are the current service designs.

New depth charge for use from greater height

In August 1943, the Air Staff decided to authorise the development of a 250 lb. A/S Bomb which was to meet a comprehensive list of requirements. It was realised that this could only be a long term development, and as it was necessary to have as quickly as possible an A/S weapon capable of being dropped from a height of of 1,500 feet or so to enable the attacking aircraft to avoid U-boat anti-aircraft fire, it was decided that as a short term policy a new depth charge should be developed. This depth charge was to be similar to the Mark XI except that it was to be capable of being dropped from a height of 1,500 feet and it was to have a terminal velocity of at least 1,000 ft./sec., since this was the minimum T.V. setting of the bombsight then in use.

The advice of R.A.E. was sought in meeting this T.V. requirement, and the adoption of a radius on the nose of approximately 10 per cent. of the diameter was recommended, this being sufficient to reduce the drag to about 25 per cent. of its former value. The question then arose as to what effect this radius would have on the underwater behaviour, and small-scale trials were put in hand at A.R.L. on models having a radiused nose and a square-edged nose, the latter on the assumption that a fairing with the radiused nose necessary for air flight had been removed on impact with the water. To avoid delay, full-scale models were put in hand simultaneously in the expectation that one type or the other would prove satisfactory. However, it turned out that neither type would fire shallow, firing depths of 70 and 80 feet being obtained on many occasions ; this was unexpected, and was ultimately shown to be due to the large entry angle (to the horizontal) of the trajectory. The early success with the Mark XI type was undoubtedly due to the asymmetry of the force on the nose during the initial stages of impact at a low angle ; with increasing angle, the asymmetry is diminished, and the couple exerted is then not sufficient to initiate (at any rate every time) a broadsiding motion. This gave the clue to correct performance—the shape of the weapon must provide the necessary asymmetry, as is done in Aircraft Mines ; an angle of 5° for the face of the nose to a plane transverse to the axis was, however, considered sufficient, as a larger angle might result in too great a scatter in a stick of depth charges.

Small-scale and full-scale confirmatory trials were carried out with gratifying results, firing depths of 15–20 feet being obtained in drops from 1,500 feet at speeds from 120 to 200 knots (maximum striking velocity 425 ft./sec. and maximum angle 60° to horizontal). By the time this weapon (designated Depth Charge Mark XIV was ready for service, the need for it had passed but a new requirement had arisen for a depth charge having two (selectable) firing depths, the second and deeper depth being to enable the aircraft to strike at U-boats at ' Schnorkel ' depth. The necessary modifications to design to enable two pistols to be used side-by-side were put in hand, and the Mark XV Depth Charge (fitted with Tail Mark V with twin air vanes) was evolved, but had not reached the stage of acceptance trials when hostilities ceased.

Trials to ascertain how far the requirement for terminal velocity had been met showed that the T.V. was of the order of 900 ft./sec., the failure to achieve the expected result (approximately 1,200 ft./sec.) being attributed to lack of stability ; the weapon, however, was considered acceptable in this respect. This lack of stability was ultimately confirmed by R.A.E. by recording the oscillations of the weapon when dropped, and also by wind tunnel experiments ; in the latter, various schemes to improve stability were tried but without much success.

Investigation of pressure explosions on impact

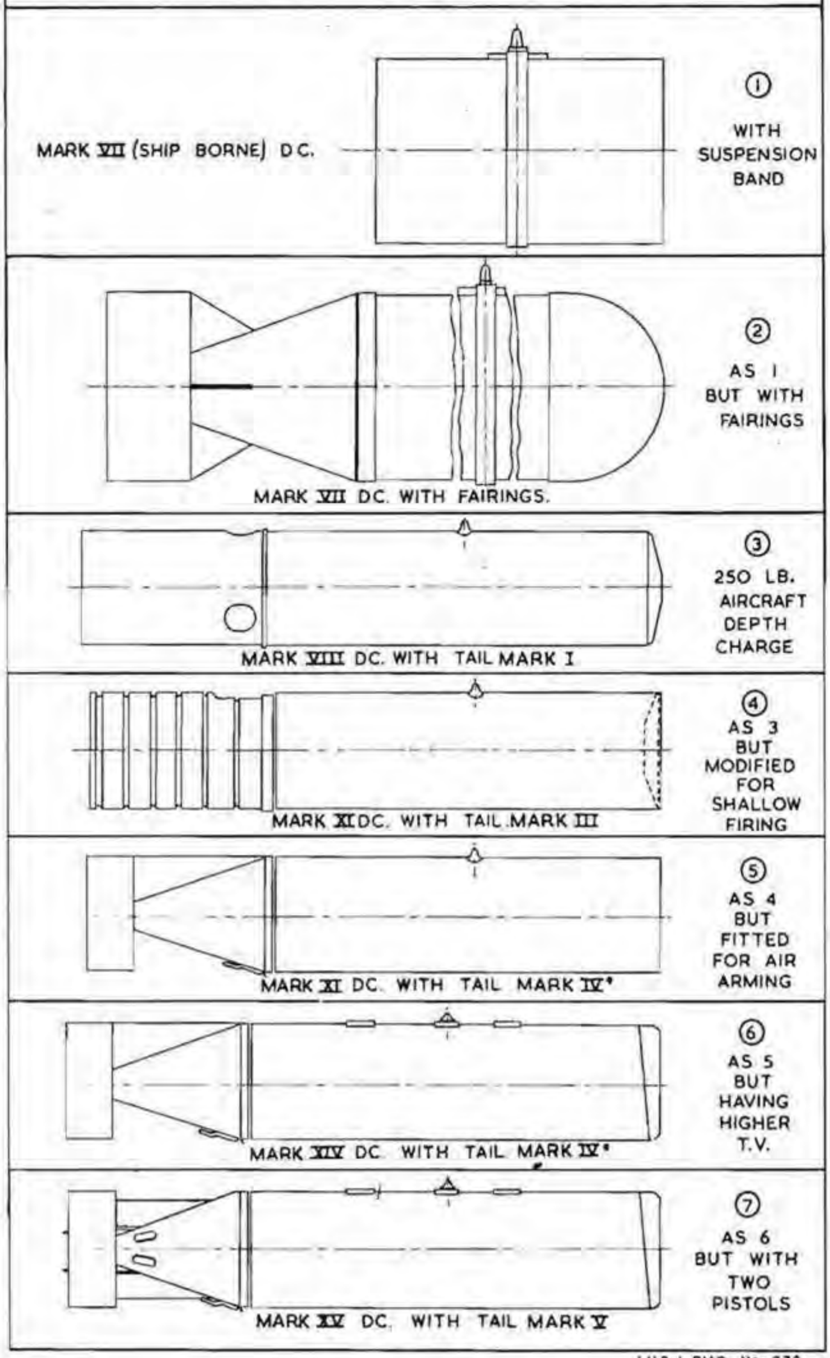
Having covered the progress of development more or less chronologically, it is necessary to return to the matter of premature explosions which has already been mentioned. The first accident of this nature occurred during trials of Mark VIII depth charges by H.M.S. *Vernon* (M) in October 1941, and since that date about two dozen incidents of this nature have been reported involving every type of depth charge and pistol that has been used. Several of these incidents have been investigated at meetings and others at the air-stations concerned but no satisfactory explanation of their cause has been forthcoming. Although incidents have occurred at moderate or even low striking velocities, it seemed reasonable to assume that they would be more likely to occur under the influence of the greater stresses and inertia forces set up due to high striking velocities but trial drops giving striking velocities well in excess of the maximum permitted in service have failed to yield any information, even when material known to be inferior in certain respects has been employed.

It is known that Torpex as a filling is liable to detonate if subject to the shock of a weapon striking a hard target at a high enough velocity, but the shock on striking water is only a fraction of that experienced in such circumstances. It is also known that the design of detonator is not such as would be recommended for use when severe shocks are involved, but a percentage of each lot of detonators are subject to severe shock tests and no lot is accepted for service if a single fire occurs in that test.

Trials have been carried out to ascertain if the fault could lie in the pistol, but while this is not impossible, no trial has given any indication that the pistol is a likely source of the trouble. Despite extensive investigations, therefore, the matter has reluctantly had to be left in this inconclusive state, though if development of the weapon were to continue there would be a strong case for altering the design to keep the explosive train broken until the depth charge was subject to hydrostatic pressure, since with this arrangement firing of the detonator on impact from any cause would result in a ' blind.'

ATTACHMENT TO APPENDIX 2

STAGES OF DEVELOPMENT OF AIRCRAFT DEPTH CHARGES



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APPENDIX 3

THE EVALUATION AND TESTING OF INCENDIARY BOMBS

In March 1946, the Incendiary Bomb Tests Panel of the Directorate of Scientific Research, M.A.P. issued a valuable and detailed monograph on ' A Study of Testing Methods (of incendiary bombs) used between 1935 and 1945.'[1]

This monograph is of such interest to every student of incendiary warfare that it is reproduced here in full, but without some of the long appendices.

Introduction

Fire has always been the enemy as well as the friend of mankind. Time and time again it has destroyed the fruits of his labours, and wiped whole cities from the face of the earth. On the night of the 3rd September, 1666, for example, a small fire broke out in a baker's shop near London Bridge, and, in Dickens' graphic words, ' it spread and spread, and burned and burned, for three days.[2] The nights were lighter than the days. In the daytime there was an immense cloud of smoke, and in the night-time there was a great tower of fire mounting up into the sky, which lighted the whole country landscape for ten miles around. Showers of hot ashes rose into the air and fell on distant places ; flying sparks carried the conflagration to great distances and kindled it in twenty new spots at a time ; church steeples fell down with tremendous crashes ; houses crumbled into cinders by the hundred and the thousand. The summer had been intensely hot and dry, the streets were very narrow, and the houses mostly built of wood and plaster. Nothing could stop the fire, but the want of more houses to burn ; nor did it stop until the whole way from the Tower to Temple Bar was a desert, composed of the ashes of thirteen thousand houses and eighty-nine churches.'

This historic fire evidently started in a small way. It probably started accidentally in the baker's kitchen, and grew until the whole room was on fire ; then the fire spread upstairs (or downstairs) and involved other rooms ; eventually the whole house was ablaze. The fire then spread to adjacent houses, and to houses on the other side of the street. Very soon new centres of combustion were initiated by flying brands in houses already heated up in preparation ; before long, these new fires joined together, kindled new ones, and swept over whole districts until there was nothing left to burn.

Now any attempt to reproduce such a sequence of events deliberately must involve an exact knowledge of the mechanism of fire-growth and spread at each successive stage. Only when such knowledge is available can full advantage be taken of the undoubted possibility that a small fire can grow into a conflagration under certain conditions. The fact that catastrophic fire-storms were only produced on a few occasions in Germany shows that, while they are still possible, we do not know enough about the conditions which govern their development to be able to guarantee results. The survey of incendiary bomb testing which has been attempted in this monograph will show that, while we have established fairly accurately the mechanism of fire-growth in a single room from a small primary fire, we still know very little about the way in which it spreads through the house, and still less about the way in which it spreads to neighbouring houses. A number of noteworthy attempts have been made to fill these gaps in our knowledge but the field for further investigation is a very wide one.

The organisation of incendiary bomb development and evaluation

The responsibility for initiating the development of an incendiary bomb of a certain type was normally within the province of the Director of Armament Requirements (D.Arm.R.), at the Air Ministry. This requirement was passed to the Director of Armament Development (D.Arm.D.) at the Ministry of Aircraft Production (M.A.P.), who then informed the Ordnance Board (O.B.). The Chief

[1] A monograph compiled by C. R. Stanbury, A.R.C.S., B.Sc., in collaboration with the Chairman and Members of the Incendiary Bomb Test Panel.

[2] *A Child's History of England*, by Charles Dickens.

Engineer and Superintendent of Armament Design (C.E.A.D.) was then asked to prepare a design in consultation with the Chief Superintendent of Armament Research (C.S.A.R.) and the ball was set rolling. During the war this procedure was often modified considerably in the interests of economy in time. Many developments were carried through directly by D.Arm.D. in conjunction with the Trade, whose research and manufacturing experience was fully utilised.

As the design progressed, a number of organisations with specialised knowledge and facilities were called in to help with various aspects of development and testing; thus ballistic problems were referred to the Royal Aircraft Establishment (R.A.E.), at Farnborough; roof penetration tests were carried out at the Road Research Laboratory (R.R.L.) at Harmondsworth; and dropping trials were done by the Aircraft and Armaments Experimental Establishment (A. & A.E.E.), at Boscombe Down. The evaluation of incendiary performance—with which this monograph is chiefly concerned—was initially the function of the Pyrotechnics Branch of the Armaments Research Department (A.R.D.) at Woolwich.

For some years prior to the war there was also considerable interest in incendiary bombing from the defensive aspect, and experimental work was organised by the Incendiary Bombs Committee (I.B.C.), of the Air Raid Precautions (A.R.P.) Department of the Home Office (H.O.), and was largely carried out at A.R.D., Woolwich. This work was extended when the war broke out, and some of it was taken over by the Research and Experiments Department of the newly formed Ministry of Home Security (M.H.S.). This Department had been divided into a number of Divisions, two of which were specially interested in incendiary bombs, namely, F. Division, which was concerned with the study of all kinds of fire problems, and R.E.8, which carried out the analysis and interpretation of photographic air raid cover, and was in direct liaison with the Air Ministry. By the beginning of 1942, the I.B.C. became an integral part of 'F' Division, and for some time was the only common meeting ground for those concerned with the fire-raising aspect of incendiary bomb development. It had representatives from the H.O., M.H.S., M.A.P., O.B. and A.R.D.

In February 1942, the problem of incendiary bomb evaluation became acute, and the I.B.C. appointed a Proof Tests Panel to study the problem, and to design a standard proof test for small incendiary bombs. The experimental work involved was co-ordinated by F Division, and carried out for them at the Fuel Department of Leeds University, and at the Forest Products Research Laboratory (F.P.R.L.), at Princes Risborough. As the work progressed, the Panel was expanded in membership to include representatives from M.H.S., O.B., M.A.P., A.R.D., and F.P.R.L., and in March 1943 it became an independent panel of F Division known as the Incendiary Bomb Tests Panel (I.B.T.P.).

It was recognised that many full scale tests would be required which would involve rapid rebuilding and reconditioning between tests. It was decided, therefore, to make use of the facilities at the Building Research Station (B.R.S.), at Garston. The fire test house known as 'I.B. Cottage' was built there, as well as five German-type attics and four single-storeyed Japanese houses. A further test house was erected at Tondu, Glamorgan, to which place the Pyrotechnics Branch of the A.R.D. had been evacuated from Woolwich. This house was built so that bombs could be fired down into it from a mortar. The designs for all these houses were produced by the architects attached to the staff of R.E.8.

The staff at B.R.S. also assisted in the many full-scale tests which were held in bomb-damaged houses in Hammersmith and North Kensington. These houses were requisitioned for the purposes, and all the necessary repair work was carried out by Heavy Rescue Squads of the Civil Defence Services in the Boroughs concerned. Damaged furniture was supplied by a number of London Boroughs by arrangement with M.H.S.

In October 1944, the I.B.T.P. was transferred from M.H.S. to the Directorate of Scientific Research of M.A.P. and was still further widened in its membership and its scope.

Representatives of the Chemical Warfare Service (C.W.S.), of the United States Army, and of the Office of Scientific Research and Development (O.S.R.D.), who were both concerned with incendiary bomb development and evaluation in America, continually served on the I.B.T.P. and kept us fully informed of their own progress.

This work was carried out at the H.Q. of the C.W.S. at Edgewood Arsenal, Maryland, and by a number of private firms under contract from the National Defence Research Committee (N.D.R.C.) working under O.S.R.D.

In 1944, a joint C.W.S./N.D.R.C. incendiary evaluation project was established at Edgewood, chiefly for the purpose of studying fire-raising in industrial targets. A representative of the I.B.T.P. worked continuously with this group, and other representatives paid short visits from time to time. The project was closed down in October 1945.

Incendiary bombing in World War I

The possibilities of fire-raising on an extensive scale with aircraft incendiary bombs were first realised in the latter part of World War I.

In this country it was thought that a large number of very small units would be more effective than a small number of large units of the same total weight, and the ' Baby ' incendiary bomb, weighing about 6 oz., was accordingly developed. It consisted of a thin aluminium tube filled with cendite, a mixture of thermite (aluminium and iron oxide) with barium nitrate, which was ejected from an outer tinplate container by a small explosion initiated by the impact of the bomb.

Aircraft incendiary bombs used by the Germans contained liquid hydrocarbon as the main incendiary, but late in the war they concentrated on the use of magnesium alloys, and by 1918 were ready to go into production on a large scale with an incendiary bomb weighing 1 kilogramme, almost identical in design with that used with such effect in the early raids on this country in World War II. Specimens of it were examined in 1921 at Woolwich, and also by the French authorities at Bourges, who later adopted it as one of their service incendiaries with some small modifications of the filling and fuze.

At Woolwich many tests were made to compare the incendiary performance of the British and German bombs, and other possible incendiary agents such as phosphorus, oil, etc. were also studied. In one typical test a number of incendiaries were compared when burning

(*a*) On a sheet of iron 1/10th inch thick.

(*b*) On a dry deal board ¾ inch thick.

(*c*) Under a wooden structure consisting of ¾ inch thick deal boards previously dried.

Phosphorus was found to be quite ineffective, and thermite, while capable of burning through the iron sheet, did not start a continuing fire in the wood owing to its rapid and highly localised action. A mock-up magnesium bomb only burned a hole through the deal board, but it set fire to and completely destroyed the wooden structure. The ' Baby ' incendiary bomb unit only charred the wood slightly and had a very small localised action.

The British 4 lb. magnesium bomb

Owing to supply limitations in the early 1920s, Germany and the United States were the only countries who could have produced magnesium incendiaries on a large scale, but by 1934 this position had changed, and limited supplies of magnesium were also available in this country. The Air Ministry, therefore, pressed for the development of an aircraft incendiary bomb containing 1–2 lb. magnesium to take the place of the ' Baby ' incendiary bomb which the Woolwich tests had shown to be so ineffective.

The experimenters at Woolwich had already recognised that fires would only be started by the small proportion of bombs which found a ' favourable ' lodgement, and that a floor with nothing else around was not a favourable lodgement. For this reason it was decided to make the British bomb heavier and more penetrating than its German prototype, so as to insure its arrival in a furnished room. A total weight of 3–4 lb. was envisaged.

In the first design it was proposed to use 1·8 lb. of magnesium, whereas the German bomb contained only 1·3 lb. In another weapon which was being considered at the time—the 25 lb. bomb which burst open on impact and ejected a number of separate incendiary units—the amount of magnesium in each individual unit was 11 oz. It was obvious that the optimum amount of magnesium had not been established and at the very beginning of the development experiments were carried out to determine the smallest amount of magnesium that could be used with success.

These early tests were necessarily closely bound up with such factors as the burning properties of the filling composition, and the ratio of filler to magnesium. If all the magnesium is to burn quietly and completely, the rate of burning of the filling must be carefully controlled ; if it burns too quickly, magnesium is wasted by spluttering, and the residual pool may even solidify again when the composition is exhausted ; if it burns too slowly, the magnesium may not melt at all. The tests were therefore largely designed so that observations could be made of

(*a*) The time and manner of burning of the filling composition.

(*b*) The time of first appearance of molten magnesium.

(*c*) The rate of burning of the magnesium and the shape and size of the molten pool.

(*d*) The total effective burning time of the molten magnesium.

The tests were carried out on a flat board, 2 feet square, which merely served as a support for the bomb and did not enable any estimation of fire-raising ability to be made.

At a later date an attempt was made to study the way in which fires were actually started, using a wooden structure which became known as a ' what-not ', from its resemblance to the article of Victorian furniture of that name. It consisted of two vertical boards, 3 feet high and 18 inches wide, set at right angles and supporting two horizontal ⅝ inch wooden shelves, 18 inches square, and 1 foot apart. It was placed so that a bomb on the upper shelf was protected from the wind.

The results of some tests carried out at Woolwich on 19 February 1936, are given in detail in Table No. 1 as an example of the sort of observation that was made, and the results that were obtained.

Table No. 1

Incendiary Unit.	Result of Test.	Reference to Photographs.
Mock-up magnesium bomb similar to the German 1 kg. bomb.	The molten magnesium burned for 11 min. At 5 min. flames appeared beneath the upper platform and a hole about 14 in. by 5 in. was eventually burned through. There was extensive charring of the vertical boards, but no continuing fire.	No. 1A. Start. No. 1B. 5 min. No. 1C. End (from underneath).
Unit from the 25 lb. bomb (Fire-pot).	Flames appeared beneath the upper platform at 4½ min. and an irregularly shaped hole, about 9 in. by 9 in., was finally burned through. The unit burned for 12 min. There was only a light discoloration of the vertical boards and no continuing fire.	No. 2A. Start. No. 2B. 5 min. No. 2C. End (from underneath).
2 lb. pellet of thermite.	The pellet burned fiercely and was exhausted in 10 sec. It had burned through the platform, and molten slag ran to one side and ignited one of the vertical boards which burned for 6 min. and then went out. Slag which dropped to the lower platform caused charring but no ignition.	No. 3A. ½ min. No. 3A. 2 min. No. 3C. End (from underneath).
1 lb. pellet of therm-alloy (a mixture of thermite with about a quarter of its weight of sulphur).	The composition burned out in 12 sec. and hot ash burned through the upper platform in 27 sec. making a small hole. The vertical boards were only slightly charred and there was no continuing fire. The lower platform was pitted by drops of burning slag.	No. 4A. Start. No. 4B. End. No. 4C. End (from underneath).

Since all four units failed to start fires which consumed the structure, it might be concluded that they were all too small. Later experience showed, however, that the vertical boards would have been consumed if they had been thinner (less than ½ inch); the conditions necessary for the establishment of continuing fires in thick timber were not clarified until some time later.

The inadequacy of these early tests was reflected in the uncertainty of the recommendations which resulted. Thus, after burning tests with bombs containing 0·9, 0·66, and 0·38 lb. of magnesium, it was reported on 13 August 1936 (D.Arm.D. file S. 32591/Part 1) that '0·66 lb. is good enough, although the 0·9 lb. is better, but not proportionately better'. It was then suggested it would be wise to use at least as much as was used in the German bomb, and it was finally decided to start making the first trial bombs with 1·8 lb., the amount first proposed.

Testing methods used in the study of civil defence against incendiary bombing

While the Service Departments were developing the British magnesium bomb, the Home Office was thinking of methods of combating the use of similar weapons by an enemy. Early in 1935 the Air Raids Precautions Department was set up and a small group of people asked to study the problem of the probable scope of incendiary attack on this country and to suggest effective methods of defence. The 1 kg. magnesium bomb was considered to be the chief menace, and trials were immediately arranged to determine the conditions under which fires could be started and how they could best be attacked. As the work progressed it became apparent that it would be necessary to call on specialised advice from a number of sources and on 18 October 1935, the Home Office formally established the Incendiary Bombs Committee with the following terms of reference:—

1. To ascertain the penetration powers of the lighter incendiary bombs (the heavier types being done at Shoeburyness) in regard to the roofs of dwelling houses, factory buildings, etc., and roofs of petrol and oil tanks.
2. To test the means proposed for protecting the roofs of explosives buildings and other buildings containing vulnerable material.
3. To ascertain any practical means of extinguishing or removing burning incendiary bombs of different types by means that could be employed by householders, at factories and by fire brigades, and means for coping with resultant fires.

The results of the trials carried out for the Committee by the A.R.D. Woolwich, are given in four very complete 'Progress Reports on Methods of Defence against Incendiary Bombs—No. 1—April 1936, No. 2—August 1936, No. 3—November 1937, and No. 4—September 1939', to which the reader is referred for much useful information.

It was pointed out in the First Report that it would be difficult to aim any of the small incendiary bombs with accuracy whatever dropping methods were adopted, so that they would most likely be scattered broadcast on targets of considerable area which would of necessity include a large proportion of residential property. This was a fundamental observation—and one which was confirmed in subsequent practice—since it determined for a very long time the type of structure which could be used as a test target, *i.e.* the attic space or furnished room of the ordinary domestic house.

At first, two small test structures (*see* First Report) were used, one identical with the 'what-not' referred to previously, and the other representing a ⅝ inch attic floor, 3 feet square, mounted on joists with a lath and plaster ceiling underneath. This was adopted on the advice of 'experts' to represent *boarded* attics in this country, since it was considered that the space between the flooring and the ceiling underneath was a particularly vulnerable one.

The tests in which the bombs were burned on a ⅝ inch floor board of the first type of test structure showed, as before, that the thermite and thermalloy burned holes through the board but generally failed to start continuing fires. A magnesium bomb in some cases burned through the board and burned away the two vertical boards alongside, but in others was unable to start a continuing fire. An interesting observation was that, even when a hole was burned through, only a little magnesium fell through the hole ; this was ascribed to the formation of a more or less firm cake of slag over the hole. Oil and phosphorus ignited the wood but the fires did not continue and left the wood only charred.

The tests on the second type of structure led to the conclusion that a magnesium bomb ' may be expected to burn through flooring boards but not through the ceiling below. The fire produced in the flooring boards would, under favourable conditions, be expected to spread '.

These results lead to an examination of floor coverings which would prevent the bomb from burning its way through into the space between the flooring and the lath and plaster ceiling below, and a British Standards Specification (B.S.S./A.R.P.47) was produced to which all such coverings had to conform if they were to be approved. Practical consideration prevented the use of these protective coverings on any appreciable scale, but in some cases they were mistakenly applied to floors which had no lath and plaster ceiling underneath, and, in others, to floors which were too thick for the bomb to burn through.

In the Third Progress Report a description is given of two further targets which were used. The first of these consisted of a 3 feet by 3 feet wooden floor, ⅝ inch thick, supported on joists with a lath and plaster ceiling underneath, and with two vertical wooden walls meeting at an angle. It was used mainly for testing the efficacy of boarded attic floor coverings. The second was a small triangular eaves-type structure, 6 feet high, 8 feet wide and 8 feet deep, boarded on the underneath of the joists with ⅝ inch boards, and covered on the outside of the rafters with ½ inch boards. One end was closed with corrugated iron sheet. When a magnesium bomb was burned on the floor of this structure, the roof boards were rapidly ignited and a destructive fire was produced in a very short time ; it was evident that the floor could be made to burn when the burning roof boards were radiating heat down, and the enclosure was full of flame.

This idea was followed up by carrying out tests in a small hut, 10 feet by 10 feet by 8 feet 9 inches high, furnished as a bedroom. Incendiary bombs of all types were placed on such places as a chair seat, table, or bed, and fires were caused that might have been destructive had they not been put out quickly to save the room for further tests. It was realized even at this stage, however, that fires which looked dangerous after two minutes might not necessarily spread and involve the whole room. Later experience showed that very few fires started by small incendiary bombs got out of control in less than 15 minutes.

Arrangements were immediately made therefore for the erection of a more elaborate fireproof building in which tests could be conducted repeatedly. This building is described in the Second and Third Progress Reports. It was divided into two parts by an incombustible partition, the part in front being used for the accommodation of observers. The rear part was fitted with a wooden floor, lath and plaster ceiling, a partly boarded attic space above, and a tiled roof in accordance with specifications given by BRS. As the constructional timber was unseasoned, the building was dried by means of a coke brazier to an average moisture content of 13½ per cent. (based on the dry weight) before the tests were made. The room below the attic was furnished as a bedroom.

Tests were also carried out in two condemned houses in Mullins Path, Barnes, on 4 February 1937, chiefly to test the efficiency of untrained volunteer fire fighting crews. The rooms were furnished and the timber was rather damper than in the test house but was considered dry enough to be comparable with timber in occupied houses.

The results of all these trials gave considerable support to the view that an incendiary attack with magnesium bombs on domestic houses could be adequately dealt with by local fire patrols of householders armed with such simple appliances as sand containers and hand pumps, supported by a smaller number of special patrols provided with larger pumps to deal with the more serious fires. As, however, the bombs were usually attacked before the fires had become serious, nothing much was learned from these tests of the mechanism of fire-spread in rooms or attics, and the exact conditions under which an individual bomb would start a destructive fire were still rather in doubt.

Burning tests carried out at the Forest Products Research Laboratory

In 1941 the emphasis had again shifted to the offensive rather than the defensive aspect of incendiary bombing and, at the request of the Ordnance Board, tests were carried out at FPRL with the object of comparing the fire-raising capacities of British and German magnesium bombs with the American steel-cased thermate bomb (thermate is a mixture of 80 parts thermite with 15 parts barium nitrate and small amounts of aluminium flake, sulphur, and castor oil). The results of these tests are described in four Progress Reports, No. 1—6 January 1941, No. 2—12 July 1941, No. 3—1 July 1941, No. 4—20 January 1942.

In the First Report a description is given of the standard test structure adopted. In Panel Report No. 3 it was explained that in developing this structure it was assumed that the average target was that found in a medium-sized space or room with a wooden floor and vertical woodwork in the shape of doors, panelling, furniture, packing cases, etc.; it is the vertically disposed timber which is generally responsible for the rapid initial spread of fire in a building. In the test, therefore, the bomb was burned on a wooden base at a distance from some vertical panels of light woodwork intended to represent, on the average, the vertically disposed combustible material in a room. The structure consisted of two slatted walls, 2 feet apart and 4 feet high, made of 2 inch slats ½ inch thick placed ½ inch apart, rising from opposite sides of a base, 2 feet square, of ⅞ inch planed Archangel redwood; the centre board of the base was 10½ inches wide to avoid a joint near the centre of the collapsed bomb. The bomb was burned in a vertical position in the centre of the base. The moisture content of the structure was estimated at 12 per cent. 'The comparative value of the bomb was assessed on (1) the time taken to burn through the floor and (2) the maximum distance at which the side panels were ignited sufficiently to continue burning, and therefore spread the fire.'

The distance apart of the panels was found to be critical, and would have required considerable alteration for bombs with much greater or much smaller fire starting efficiencies than those used. It is interesting to note that this very property, *i.e.*, the distance from an incendiary bomb at which a thin wood board can be ignited, was afterwards adopted as the best criterion of its fire-starting efficiency in domestic targets.

In the Second Report it was decided that the vertical position of the bomb was unsuitable and tests were consequently made with the bomb horizontal, parallel to, and equi-distant from the two side panels; the structure with the bomb on it was weighed at intervals during the burning. In some of the tests the distance between the panels was varied; thus with either British or German magnesium bombs the panels were burned out if they were only 26 inches apart but not if their spacing exceeded 28 inches. There was some doubt as to whether ignition was produced by radiation from the burning bombs or by spread of flame across the floor, and in later tests strips of the base, 2 inch or 3 inch wide, nearest the panels were given one coat of silicate paint to prevent any slow surface spread of flame across the base.

The tests described in the Third Report were made with the panels 26 inches apart. A German 1 kg. bomb and several different varieties of the British 4 lb. bomb were burned. As before, the results were somewhat varied; sometimes both panels were burned out, sometimes only one, and sometimes neither. In two tests with the side panels only 24 inches apart no burning out occurred contrary to the finding of the Second Report.

The Fourth Report described further experiments on the burning of American steel-cased thermate bombs and British magnesium bombs on the standard test structure with panels 26 inches apart. Burning was less severe than in the previous tests of these bombs and it was suggested this was probably due to the low (winter) temperature at which the tests were carried out (in the open), whereas the earlier tests had been made in the summer.

Throughout the whole series of tests it was apparent that the effect of chance variations on the results was considerable. Apart from differences between individual test structures which could not be avoided with a natural material like wood, the burning of all these bombs had accidental features, particularly as to the details of the subsidence of the melting bomb and the shape of the resultant pool, which affected the results. It was obvious that a much larger number of tests would be required to establish the existence of significant differences between the incendiary efficiencies of the various bombs, and that these would have to be done under very carefully controlled conditions.

Early work of the Proof Tests Panel of the Incendiary Bombs Committee

The tests at F.P.R.L. had been witnessed by a number of people interested in incendiary bomb development, and the results had been widely discussed (*see* OB Proc. 16,833). By this time, however, the Ordnance Board was interested not only in the intrinsic efficiencies of the different bombs tested, but also in their relative values in terms of the number of destructive fires which could be started in an operational attack with a given aircraft load. So far it had been impossible even to attempt an answer to the second part of the request, and the first part had only been answered indifferently and not very conclusively. It was felt that the method of test itself warranted much fuller study before it could be said with conviction that one bomb was superior to another in its fire-raising power. Acting, therefore, on the suggestion of the Chairman of the Incendiary Bombs Committee, a Proof Tests Panel, was set up on 11 February 1942

> 'to develop a standard proof test for comparing small bombs or small components of large incendiary bombs and to report to the Incendiary Bombs Committee '.

A few months previous to this, F. Division had enlisted the help of the Fuel Department at Leeds University in their study of incendiarism, and one of their first investigations was a measurement of the radiation and convection isotherms round a burning German 1 kg. bomb. It was agreed that the results of this work should be reported to the Proof Tests Panel in due course.

At the request of the Panel a number of possible tests were considered by FPRL and the results of these considerations were given in Panel Report No. 4. A description was given of tests in which known amounts of incendiary materials magnesium and benzene were burned on incombustible surfaces below a standard 'crib' of sticks of wood which was suspended from the arms of a balance so that the progressive loss in weight could be measured. Various forms and sizes of crib were used, and conditions of air flow, wood moisture content, etc., were all carefully controlled. This test suffered from the obvious limitations imposed by the differences in the manner of burning of liquid magnesium and benzene vapour and the difficulties of igniting small amounts of magnesium, and it was finally abandoned as it was felt that the results could not be related closely enough to practical conditions. The Ordnance Board representative on the Panel pressed strongly for the use of the actual bomb in any other test which was tried.

Shortly after this the results of the measurements of the radiation and convection isotherms of burning magnesium at Leeds became available and were given to the Panel in Report No. 2. The method used was as follows :—

50 gm. of magnesium was placed in a small cavity in a refractory insulating brick and melted as quickly as possible with an oxy-acetylene blow-pipe flame. A period of approximately one minute was allowed to elapse before measurements were made so that equilibrium conditions could be reached. An arm rotating about an axis through the centre of the pool of liquid metal carried a linear thermopile and a small insulated frame supporting a calibrated thermocouple. By varying the positions of the thermopile, and of the frame carrying the thermocouple, and by varying the angle of the rod with respect to the vertical axis through the pool, it was possible to make measurements at any point in the quadrant of a circle between the horizontal and vertical axes.

At equal distances the radiation temperature immediately above the pool exceeded that in the horizontal plane of the pool. At 1 metre distance, for example, the measured radiation temperatures were 160° C. (above), and 70° C. (to the side) ; a radiation temperature of 300° C. was attained at 48 cm. above the pool and at 22 cm. horizontally from its centre. Slightly higher radiation temperatures were found for a thermite bomb during its brief period of burning.

The temperature of the convected gases had dropped to 400° C. at 30 cm. above the centre of the bomb pool and at 10 cm. horizontally from the centre. At about 15 cm. above the pool the 'convection' temperature was 800° C.

Similar results were obtained with tests with 1 kg. German bombs, and it was at once obvious that a pool of burning molten magnesium is not an ideal incendiary agent since it has a more pronounced effect above than to the side, and the chances of such a bomb getting underneath furniture are small. Moreover, calculations based on the measured radiation and convection temperatures showed that not more than 20 per cent. of the total heat available (about 20,000 B.Th.U.) is dissipated by radiation and convection to the surrounding atmosphere. The remaining 80 per cent. is conducted through the molten metal to the supporting floor in about 10 minutes, a mechanism which can be likened to the action of a flat-iron. The actual rate of generation of heat is many times greater than the minimum which is known to be necessary for the ignition of wood, but the heat reaches the floor in the absence of air and at such a high temperature that the wood is merely charred ; some combustion takes place at the edge of the pool, but the draught upwards from the heated pool tends to draw the flame away from the surrounding floor towards the centre. The net result is that the wood chars, and may char right through if it is thin enough, but a continuing fire is very rarely started ; only occasionally does the floor collapse under the weight of the light ash, and if collapse does not occur the chance of a continuing fire depends on such imponderable factors as the presence of joints or cracks in the floors which may lead to destructive burning on the underneath.

The study of the mechanism of starting fires

In March 1942, it was known that continuing fires could not be started in isolated wooden floors unless (*a*) they were closed over with some combustible surface such as the roof boards of the eaves structure or (*b*) they were thin enough for the magnesium to burn through and lodge in some confined space such as the space between a boarded attic floor and the lath and plaster ceiling underneath. Small fires had been started in a number of furnished rooms, but they had usually been extinguished before they had grown to appreciable proportions. Nevertheless at this time we had already experienced extensive raids in this country, and many destructive fires had been caused by magnesium incendiary bombs. The question was—' what other conditions must be operative before a magnesium bomb burning on a wooden floor can start a continuing fire ? '

Tests carried out at Leeds showed that if the floor boards were dried down to 2–3 per cent. moisture content, the floor would continue burning after the bomb was exhausted. The lowest value one can hope to find in the average furnished house is, however, about 8 per cent.

On another occasion a magnesium bomb was ignited on a small section of boarding about 18 inches square, supported at the corners on bricks standing on a wooden floor of normal moisture content : it was then found that flame penetrated to the underneath of the small section and ignited the floor below, causing a fire which had to be extinguished before the whole floor was involved. This result was reminiscent of that obtained at Woolwich with the eaves structure, and it indicated that a floor of normal moisture content could be made to burn if its combustion was aided by the absorption of heat from neighbouring burning material.

In another experiment three bombs were placed, 3 ft. apart, in the same room ; one on the open floor, one close against a vertical board ¾ in. thick, and one at a distance of 1 foot from a wooden structure 2 feet by 2 feet by 3 feet having a light vertical panel on the side towards the bomb. The bombs were fired simultaneously but only the third produced a continuing fire ; the light panel was ignited and the heat thus produced supported the growing fire in the rest of the structure and in the floor beneath. The ¾ inch thick board burned while the bomb was burning and the fire then went out. This suggested that a magnesium bomb is only capable of starting a continuing fire in thin timber and that without such a fire it is impossible to build up the fire in the floor to the continuous and destructive stage.

With these experimental results in mind, some theoretical consideration was given in Panel Report No. 6 to the problem of the continued propagation of flame through an isolated piece of wood. This led to the conclusion that a continuing fire could only be established in a wood panel if it was below a certain critical thickness. Of the heat evolved at the surface of a burning panel, only about 15 per cent. is passed inwards to the unburnt material, the remainder being dissipated by radiation and convection. Unless the amount of heat passed to the next interior layer is sufficient to evaporate the water and raise the temperature of the wood to the ignition point, no continuous propagation of flame can take place. The flow of heat inwards is dependent on the conductivity of the wood and the temperature gradient established. Although wood is a poor conductor of heat, it is nevertheless greatly superior to air ; with a thick piece of wood heat is conducted away from the burning surface too quickly for it to heat up the intervening layers to the ignition point ; with a thin panel the heat is soon held up at the far side since air is such a poor conductor, and the temperature rapidly rises to the ignition point. Using a magnesium bomb as the source of radiation on one side of a wood panel, it was found experimentally that the maximum thickness in which a self-propagating fire could be produced was ½ inch. With vertical wooden furniture supports such as a chair leg, where the heat is not confined to one side, a greater thickness is allowable, but it was shown in Panel Report No. 145 that for square sections of 1¼ in. and above, a continuing fire could not be started even when the bomb was touching.

The conditions for the development of a fire in a wooden structure composed of more than one piece of wood are more complex because the heat lost to the surroundings from one piece is affected by the heat liberated by the combustion of adjacent pieces. The general temperature level of the system is raised, and the temperature gradient through each piece of wood modified to such an extent that it becomes possible to start continuing fires in wood of dimensions and water content greater than would have been possible in an isolated panel. An interesting example of this is seen in the building of a fire in an ordinary domestic hearth. The average ' chip ' is too large in cross-section for it to continue burning on its own when it has been ignited on the surface by the burning paper ; but, when arranged with other chips in the traditional crib form so that full advantage can be taken of the mutual support which adjacent burning surfaces give to each other, a self-propagating fire hot enough to ignite the coal is soon established.

This principle of mutual support can be demonstrated very simply by igniting a few ounces of incendiary gel between two vertical panels of wood, one ¼ inch thick, and the other ¾ inch thick, placed about 2 inches apart. The inside surfaces of both panels readily inflame, and soon appear to be burning vigorously. If now the panels are separated to a distance of about 6 inches or more, all flame on the inside surface of the ¾-inch board dies out, while the ¼-inch board continues to burn, and flames frequently break through to the back face. If the boards are brought together again, the ¾-inch board will at once reinflame and the combustion of the ¼-inch board is also accelerated.

The conditions under which a small incendiary bomb can start a continuing fire may now be classified as follows : The bomb must be burning within effective ignition range of

(*a*) wood thin enough of itself to give self-supporting combustion, or

(*b*) two or more pieces of wood, too thick in themselves to give self-supporting combustion, but situated closely enough together to permit of mutual support.

Continuing the analogy of the fire in a domestic hearth suggested, it is clear that the bomb may be regarded as the ' match ' and the ' paper,' which ignite the ' kindling ' which can exist either in form (*a*) or form (*b*) ; this, in turn, ignites the heavier timbers, or ' bulk fuel ' of the room. For this reason the small incendiary bomb was often referred to as a ' match ' bomb, and the light woodwork which it was capable of igniting directly as the ' kindling.' It was clear then that the efficiency of any such ' match ' bomb could be measured by the chance it had of falling near enough to ' kindling ' to ignite it.

The Leeds ' Panel ' test

The ideas outlined were developed in a series of Panel Reports, Nos. 5, 6, 11, 12, 16 and 26a. In seeking something to represent ' kindling ' it was obvious that (*b*) was not easy to reproduce, and it was decided to use a thin plywood panel for the purpose. The experimental work was carried out at Leeds and consisted in an exploration of the maximum region round the bomb in which such a panel could be ignited, and the test became known as the ' panel ' test. The panels used were made of birch plywood, 1 foot square and $\frac{1}{8}$ inch thick, and they were used in both horizontal and vertical positions. At a later date other plywoods were experimented with and beech was used in a number of tests (*see* Panel Report No. 146). In applying the experimental results to a typical furnished room the following method was used.

First of all, on a plan of the room the location of all the ' kindling ' was marked, considering only wood within the vertical range of the bomb at rest ; for example, thin wood in the sides of a small bookshelf hung on the wall was ignored if it was above the level at which it could be ignited by a bomb on the nearest horizontal shelf below. Similarly, horizontal wood was ignored if situated too high in the room. Some suitable method was adopted for distinguishing the vertical from the horizontal ' kindling.'

The vulnerable areas were then marked in the following way. Where the effective regions measured by the ' panel ' test are clearly symmetrical about a vertical axis, as in the case of incendiary gels, they may be replaced by cylinders of radius R and height H (with suffix v or h for vertical and horizontal panels). If the regions are ellipsoidal rather than cylindrical, as in the case of a magnesium bomb, the horizontal range may be taken approximately as the geometric mean of the horizontal semi-axes, and the effective height by the vertical semi-axis. Thus, round the plan of each piece of thin vertical wood up to the height H_v, the area lying within a distance R_v was marked ; similarly round the plan of each piece of thin horizontal wood up to the height H_h, the area lying within a distance R_h was marked. Let the total area thus enclosed be denoted by A^1, and let A be the whole area of the room accessible to the bomb. Then the chance that a bomb which enters the room will be in the vulnerable area A^1 is $\frac{A^1}{A}$, and this is the probability that such a bomb will start a continuing fire in the ' kindling ' in the room. This was generally known as the ' static intrinsic efficiency ' or S.I.E. of the bomb in the target concerned.

In Panel Report No. 26a, this method was applied to a number of incendiary bombs, using a typical furnished German apartment, details of which were furnished by RE8. Report No. 26a was adopted by the Panel as a satisfactory answer to the original terms of reference, and it was communicated to the Incendiary Bombs Committee by the Chairman in July 1943. It was realised, however, that much more work on fire-spread and incendiary bomb development and testing would have to be done, and for this reason the Panel was continued as ' The Incendiary Bomb Tests Panel.'

Application of the ' Panel ' test to magnesium bombs of different weights

While the ' panel ' test was being developed at Leeds, the rapid expansion of the incendiary bomb programme emphasised the necessity for conserving magnesium, and in October 1942, the Ordnance Board made a further request that the I.B.T.P. should study the likely qualitative deterioration in effect in the incendiary efficiency of British magnesium bombs due to a reduction of the magnesium content to $\frac{3}{4}$ lb. (O.B. Proc. No. 19776.)

A number of graded magnesium bombs were submitted to the ' panel ' test, and the results given in Panel Report No. 11 in the form of a ' figure of merit '—a method which had been suggested in Panel Report No. 6, but which was later discarded in favour of the more exact method described in Panel Report No. 26a and outlined in the previous section. This ' figure of merit ' was defined as

$$K_1 V_v + K_2 V_h + K_3 A$$

where V_v = effective volume in which vertical panels can be ignited,

V_h = effective volume in which horizontal panels can be ignited,

A = area of charring of floor,

and K_1, K_2, and K_3 are weighting factors taken as 2, 1, and 0·5 respectively.

A summary of the results was given in Panel Report No. 12a, and, in addition, an estimate was made of the probable number of destructive fires which would be caused by one aircraft load of bombs of each weight. The analysis involved a certain amount of conjecture about the activities of fire-guards and the proportion of fires which would grow to the destructive stage, but in the light of later experimental work these conjectures were found to be reasonable. In the final discussion it was deduced that ' there is no gain and even a slight loss in subdividing a given quantity of magnesium into a greater number of bombs.'

It was unfortunate that this conclusion was based on a method of using the experimental results which was so soon after to be abandoned. Experience gained in the application of the method given in Panel Report No. 26a showed that, for all practical purposes, the chance of starting a fire in a furnished room was almost directly proportional to the mean horizontal radius of action R_v for vertical panels, whereas the originally proposed ' figure of merit ' was roughly proportional to the cube of R_v. The figures based on both methods of assessment are as follows :—

Table No. 2

Weight of Magnesium.		Incendiary effect relative to Mark III Bomb.	
In lb.	Relative to Mark III Bomb.	Based on ' Figure of Merit.'	Based on R_v.
Mark III 1·25	1	1	1
1·04	0·83	0·82	0·95
0·94	0·75	0·72	0·86
0·75	0·60	0·56	0·82
0·46	0·37	0·23	0·53

Thus, on the old system, as the weight drops progressively from 1 to 0·37, the incendiary efficiency falls off at a greater rate from 1 to 0·23. On the more exact system the incendiary efficiency falls off much less rapidly than the reduction in weight, and the 0·46 lb. bomb is $\frac{0 \cdot 53}{0 \cdot 37} = 1 \cdot 43$ times as efficient as the 1·25 lb. bomb. Contrary to the findings of Panel Report No. 12a, therefore, there is an advantage in further subdividing a given weight of magnesium into a greater number of individual bombs.

The full implications of this alteration in method of assessment are given in Panel Report No. 143. In actual fact, it is doubtful whether the erroneous conclusion of Panel Report No. 12a had much effect on war-time development of the 4 lb. magnesium bomb. In the Mark IV bomb the weight of magnesium was reduced to 1 lb. 1 oz., but as this was accomplished by increasing the bore and keeping the external dimensions the same, no increase in numbers carried resulted. One advantageous result was that the magnesium melted more quickly (4–5 minutes as against 10 minutes) and the chance of the bomb being found and attacked by fire-guards was reduced. Actually, this rapid burning resulted in an increase in R_v from 10½ inches for the Mark III bomb to 14 inches for the Mark IV bomb.

Possibilities of increasing the S.I.E. of a ' Match ' bomb

It is a necessary consequence of the method of assessing the chance of fire-starting by a ' match ' bomb that the chance may be substantially increased if the bomb includes a device which transfers its action from the point where it falls to a place in the room where the proportion of vulnerable to safe area is greater than for the average for the room.

Such a device was developed for the 4 lb. magnesium bomb. This bomb has two main parts, (*a*) the incendiary body, and (*b*) the steel nose which gives the bomb the necessary penetration. It was suggested that a small explosive charge should be inserted between (*a*) and (*b*) which would operate some seconds after the bomb had come to rest, and drive the magnesium body away from the steel nose and into contact with some vertical surface. In Panel Report No. 14 an analysis of the action of such a bomb in a lounge and bedroom showed that the S.I.E. could be increased by 30 per cent.

There are other incidental advantages in a separating charge. In the ordinary way about 1 to 2 inches of the magnesium body nearest to the nose fails to burn owing to the cooling action of the steel ; by separating the nose from the magnesium there is a greater chance for all the magnesium to be consumed. If the nose is of the explosive type there are added advantages in separation. Firstly, the scattering of the burning magnesium by the explosion is prevented. Secondly, the fire-guard will be ignorant of the location of the explosive nose in the room and will be more circumspect and hesitant in carrying out his duties.

The principle of the separating nose was incorporated into the German IBSEN bomb, but this was never used extensively enough to enable its effectiveness to be evaluated. Development of a British bomb on these lines was proceeding at the end of the war, and it may well be that this is the ideal small incendiary bomb, always providing its production can be made reasonably simple.

The use of a target-seeking device was developed independently in the United States and resulted in the production of the AN–M69—6 lb. oil bomb which was used so successfully against Japan. The Standard Oil Development Co. of New Jersey had carried out extensive investigations for N.D.R.C. into the possible substitution of thickened gasoline gels for magnesium as an incendiary agent. They used for their burning tests what was known as a ' half attic structure,' consisting of a floor section and a 45 degree sloping boarded roof, 6 feet high and 3 feet across. It was found that the nearer the gel was placed to the eaves line, the greater was the chance of producing a destructive fire in the structure. Thus complete destruction was attained with 1 lb. of gel at 2 feet 8 inches from the eaves, with 2 lb. of gel at 3 feet 6 inches, with 3 lb. at 4 feet, and with 10 lb. at 6 feet. In each case the floor, as well as the roof, was set alight, and the mutual support of the two fires caused the build-up to destruction, as with the tests in similarly shaped structures at Woolwich. If the amount of available gel is restricted to about 2 lb. it is obvious that, in an attic cleared of furniture, the vulnerable area is confined to a strip about 2–3 feet wide along the eaves, light doors, and partitions (if any), and this is a small proportion of the total. A bomb was therefore devised which first came to rest on the attic floor, and then ejected its contents so as to propel them substantially in one piece towards the eaves. In this way the chance of starting a fire was enormously increased.

The advantage of such a system also operates in a furnished room, but the M69 bomb was not capable of penetrating the floor of the average German attic into the furnished rooms below. It was, however, ideal for Japanese targets where a much lower penetrating power was required.

' I.B. Cottage '

Panel Report No. 12a made one notable contribution to incendiary bomb testing and development in that it stressed the need for more detailed information on the way in which a fire grows from its early beginnings to the destructive stage when the whole compartment is involved. The effect of fire-guards on a fall of incendiaries can only be assessed if, among other things, it is known how long the fire remains in the stage in which it can be easily extinguished by hand appliances.

Arrangements were therefore made for the construction of a test building in which it would be possible to let the fires develop to complete destruction of the contents if necessary. In September 1942, the fireproof incendiary building at Woolwich was transferred to B.R.S. for re-erection. This structure had been designed originally to accommodate a bedroom and roof space and was not high enough for two full floors. As this was thought desirable, the steel framework of the structure was erected on top of a brick-walled building of the same external dimensions forming the ground floor. The steel framework was filled in with brick-work panels thus providing what was essentially a two-storeyed brick building with one room on each floor. A complete description of the building is given in Panel Report No. 24 and it was ready for use in January 1943, and it was christened ' I.B. Cottage.' The extension walls were provided to allow for additional rooms to be built on if required, but this was never carried out.

Before the ' Cottage ' was used, a good deal of consideration was given to the problem of deciding how to identify, without any doubt, the critical point at which the fire got out of control of the hand appliances. It was suggested that a continuous measurement of the heat content of the gases escaping through a hole in the ceiling might provide the answer, and a 9-inch diameter hole, simulating the hole made by the bomb on entry, was left in the ceiling for this purpose. It was a straightforward matter to measure the temperature of these hot gases at intervals, but not an easy one to measure the flow. As an alternative an attempt was made to measure the air-flow into the room through a 2 feet square hole at floor level. The building however, did not lend itself to accurate measurements of this type and the project was abandoned after several attempts as unprofitable. In subsequent tests the air temperature at the centre of the room was always measured as an indication of the intensity of the fire, and occasionally the radiation intensity was measured through a window in the E wall.

The 'Cottage' had a boarded floor and a plaster-board ceiling which could be quickly replaced when damaged by fire. There was a panelled door to give the same combustible contribution as the door in an ordinary living room, since the actual door was of steel, and the furniture consisted of a table, four small chairs, two easy chairs, and two cupboards with panelled fronts. Generally no 'tinder' or hanging textiles were used since it was found in some early tests that they did not materially assist in the rate of growth of fire from a 'match' bomb, and were difficult to standardise. The furniture was built to designs given in Panel Report No. 10. The flooring and the timber for the furniture was first cut to size and then sent to F.B.R.L. to be kiln-dried and conditioned to 12 per cent. moisture content before it was assembled at B.R.S. The completed lots of furniture were stored in a dry room until they were required and only put in the 'Cottage' on the day of the test.

The 'Flash-Over'

Some preliminary tests were made during which conditions were adjusted and finally standardised. A number of tests with the standard small incendiary bombs were then made and the results found to be amazingly reproducible considering the nature of the tests; they immediately provided vitally useful information on the mechanism of fire-growth in such a room. A detailed description will be given of Test No. 5 which is recorded in Panel Report No. 30, as it illustrates exactly the conditions which were experienced repeatedly in subsequent tests with small incendiary bombs.

A British 4 lb. Mark IV magnesium bomb was placed in the angle between the cupboard and the door, and close enough to be within the effective range of action (14 inches) of this bomb for igniting 'kindling'.

The plywood panels of the cupboard and door ignited within the first minute and flames spread up the panels causing a strong fire in this corner of the room. During the first ten minutes, there was little tendency for the fire to spread away from the group of furniture in this area. This localisation in the early stages was partly due to the directive action of the convection currents; as cold air was drawn in near the floor level towards the fire it was deflected upwards at the cupboard and the door, thus directing the flames on to the panels and ceiling and away from the other contents of the room. The time-temperature curve shows that the air temperature in the centre of the room rose to 200° C. in the first 10 minutes and to 400° C. in 14 minutes. There were temporary rises at two stages during this period corresponding with observed fluctuations in the intensity of the fire.

Meanwhile, the woodwork of the furniture and floor was gradually heated up mainly by radiation, and vapours could be seen distilling from the small chair nearest the fire. Later, the same effect was seen on the much heavier timbers of the table.

At 14 minutes the framework of the burning cupboard collapsed. Almost immediately there was a rapid increase in spread of fire over the floor and furniture, and within a minute the whole contents of the room were burning fiercely. The change was accompanied by an extremely rapid rise in the air temperature to 950° C. and this temperature was maintained for a further 7 minutes until the fire was extinguished.

The temperature of the woodwork in the cupboard farthest from the fire was recorded by a thermocouple inserted in a small hole drilled just below the surface of the wood. At the time the fire began to spread rapidly this couple was registering

250°–300°C., a temperature at which wood decomposes exothermically. It may be assumed that most of the timber in the room had by then almost reached or passed this temperature, and the sudden flash of the fire over the whole room corresponded with the almost simultaneous ignition of all the exposed comoustible surfaces and the evolution of a correspondingly large amount of heat.

This point at which the fire suddenly involves the whole room has been called the 'flash-over'. It has been observed repeatedly in I.B. Cottage and elsewhere and is probably an essential feature of most fires which start from small beginnings and finally become destructive. In a room which contained a high proportion of 'kindling', it is possible that the fire would spread progressively from one piece of furniture to another, and a 'flash-over' would not take place, but such a room would be an exception. At the 'flash-over' all the combustible objects in the room not involved in the primary fire suddenly become heat producers instead of heat receivers, and there is always a sudden rise in temperature to approximately 1,000° C.

The chief interest of this phenomenon lies in the fact that it provides a clear-cut line of demarcation between fires which can be dealt with by first-aid fire-guard parties using stirrup pumps and similar equipment, and those which necessitate attack by high-powered jets such as are normally used by the regular fire brigades, and which can be operated at a distance from the fire. It has been demonstrated that even after the 'flash-over' it is possible to extinguish such a fire with stirrup pump jets in the hands of skilled and experienced operators, but the task is almost impossible to the average inexperienced operator, the 'flash-over' may therefore very usefully be taken as the dividing line between the two kinds of fire.

With all the small bombs it was found that the time to 'flash-over' was rarely less than 15 minutes and was occasionally as much as 50 minutes, depending on such factors as the intensity and size of the primary fire started by the bomb, its position in relation to other combustibles in the room, the dryness of the contents, the extent of aeration, the size of the room, etc. The size of the primary fire was specially important, and it was found that unless this involved at least one major piece of furniture such as a cupboard or an easy chair, the heat evolved was not sufficient to raise the rest of the room to the ignition point, and the fire would die out. The ignition of a single small chair for example, was generally found to be quite useless.

The long incubation period of the "match" bomb fires made fire-guard interference a serious menace to the success of incendiary attack. To detei them a proportion of the bombs had been fitted with explosive capsules containing gunpowder, and in the first 1,000-bomber raid on Cologne, a 4 lb. incendiary bomb containing a high explosive charge which detonated after a delay was brought into use. Moreover, the high explosive bombs which formed the greater part of the weight of the attack drove many of the fire-guard parties to shelter. To defeat the fire-guards two modifications to the incendiary raid technique were proposed.

(*a*) An increase in the bomb density so that the fires became too numerous for the fire-guards to extinguish before they got out of control. Improvements in target finding methods enabled this to be achieved more and more as the war progressed, and in 1944 the attacks with the 4 lb. bomb had become very destructive.

(*b*) The use of a larger bomb which would start fires which reached the 'flash-over' so quickly that they were reasonably invulnerable to fire-guard attack. The attempts to produce such a weapon are described later in this monograph.

The influence of linoleum on domestic fires

The burning tests in I.B. Cottage and the 'panel' tests at Leeds were normally carried out with the bomb burning on a plain wooden floor. Many furnished houses have linoleum-covered floors and tests were made to find out what effect a covering of printed linoleum would have on the radius of action R_v of a British 4 lb. magnesium bomb. These tests are recorded in Panel Report No. 63. It was found that the range was slightly less than with the boarded floor, and this was attributed to the suppression of flames from the floor boards which normally assist the action of the bomb, while the linoleum itself does not burn very well in the early stages.

When the American M50 bomb was used, the blobs which were scattered in the first minute or so of intense burning, gave small flames as they landed on the linoleum but the flames soon died out. No appreciable incendiary effect can be expected from this source.

It was understood that, in Germany, parquet floors and rugs were common, and that where linoleum was used it had a bitumen backing. Although the latter would add to the general heat output when the fire had passed the 'flash-over' it would hardly affect the radius of action of the bomb.

On 19 May 1944, some tests were carried out on a linoleum-covered floor at I.B. Cottage (*see* Panel Report No. 81). It was confirmed that the radius of action was smaller in this case; however, once the primary fire had become established the growth of fire to the 'flash-over' was quicker than with the boarded floor, but as the room had been partially heated by a previous test it was not possible to say how far the linoleum contributed to the spreading. In the tests in bomb-damaged houses in Rackham St. and elsewhere which will be described later in this monograph, linoleum was invariably used, but it never seemed to make any appreciable difference until the room was well warmed up.

A similar kind of effect was produced at I.B. Cottage on 1 March 1944, when a test was made using an oil-soaked floor which had been brought from a woollen mill in Yorkshire. The progress of the primary fire was the same as with the plain floor, but the 'flash-over' took place earlier and with much more violence.

The British 30 lb. gel incendiary bomb

The Germans, in their raids on this country, used several large incendiary bombs, one of the most popular being the 50 kg. oil bomb. This bomb had a thin-walled steel case which contained a sticky rubbery gel and a small amount of phosphorus. A fuze actuated by the first impact of the bomb, exploded a charge which burst open the case and ejected the contents while the bomb was still in flight.

A bomb similar in principle had been developed in this country early in the war to provide an alternative to the 4 lb. bomb in view of the shortage of magnesium. It weighed 30 lb., and contained 6 lb. of incendiary gel. Before the entry of Japan into the war, this gel consisted of benzole thickened with rubber. Scrap perspex was then used, and later a preparation of cellulose acetate.

It was soon recognised that a bomb of this size might satisfy condition (*b*) and start very rapidly destructive fires, since it was capable of starting a number of separate primary fires in the room at the same time, which might join together to form a blaze. For this reason in all the early reports, bombs of this size were always referred to as 'blaze' bombs. Later experience showed that the terms 'match' and 'blaze' were more properly applied to the fires caused by the bombs than to the bombs themselves. Thus a 4 lb. magnesium bomb burning in a room full of dry wood shavings might start a destructive fire in a few minutes, while a 30 lb. gel bomb might scatter its contents so that they all landed on incombustible surface and burned out harmlessly. At the time, however, the distinction was a useful one.

Three of these bombs were tried on 7 July 1942, in some condemned houses in Mall Road, Hammersmith, furnished to varying densities with damaged furniture made available by M.H.S.

At once it was apparent that it would be difficult to fire the bomb statically in any way which would satisfactorily reproduce its manner of functioning when dropped from the air. A number of possibilities were considered and in this first test the method used was as follows. The bomb was stood tail downwards on the floor and anchored so that when it was fired it rose 5 feet into the air and then ejected its contents downwards in a conical shower. This was achieved by attaching wire ropes to the bomb and passing them through holes in the floor and round a joist, with enough slack to allow the bomb to rise to a height of 5 feet before the slack was taken up.

One bomb did not function correctly and the resulting fire was easily dealt with. In the other two cases the fires got out of control although they were attacked by stirrup pump parties within $1\frac{1}{2}$ minutes of the firing of the bomb. In both cases the fire spread to the floor upstairs. One of the fires was extinguished by the N.F.S. but the other was allowed to burn, and eventually the whole house was gutted.

It was concluded from these tests that the 30 lb. gel bomb could be classed as a ' blaze ' bomb, although many observers were of the opinion that the rooms had been far too heavily furnished with draperies etc., and that the results should be discounted somewhat as a result.

An attempt was made on 5 March to test this bomb at I.B. Cottage. The bomb used was a Mark III bomb with a 7 per cent. perspex benzole filling, and it was placed in a bracket in the corner of the room about 6 feet from the floor with its tail pointing downward at an angle of approximately 20 degrees, and with the seam underneath. Thus, although the bomb was apparently entering the room tail first it was hoped that the ejection of the gel would be similar to the forward ejection produced in an air drop, where the high arrival velocity of the bomb (about 800 feet per second) is sufficient to swamp any backward velocity of the gel on ejection from the back end of the seam and the tail. However, when the bomb was fired, the seam did not split open, and the whole of the contents were ejected from the base and consumed in a flash-burn, which did considerable structural damage but caused no fire at all.

Another trial was carried out with this bomb as one of a series which took place in Bridge Road, Hammersmith on 8 March 1943. On this occasion the standard set of furniture designed for I.B. Cottage was used, and the bay windows were fitted with short net curtains and full length black-out curtains. The bomb was mounted in a similar manner to that used at I.B. Cottage except that it was on a ledge instead of in a bracket. Unfortunately the test was again abortive as the case did not split longitudinally, and the gel was ejected from the base. A large amount of the filling was again consumed in a flash-burn which caused considerable material destruction, but the few small fires which were started were easily extinguished. It was pointed out that, in any future test the bomb should be artificially cooled before use to a temperature of about $-40°$ C. such as they would have in operational practice after a long flight from England, since this would materially affect the viscosity and consequently the degree of break-up of the gel, and prevent its explosive dispersal.

As the results of these trials showed that it was probably impracticable to devise a means of functioning this bomb statically in a manner adequately reproducive of its action when dropped from the air, it was agreed on the 18 March 1943, not to carry out any more tests with statically fired bombs, but to proceed with the erection of a mortar at some suitable place so that bombs could be fired downwards into a test building, and the correct distribution of gel reproduced.

A test carried out at I.B. Cottage with cellulose acetate gel on 4 June 1943, showed that 2 lb. was probably about the minimum amount which could be relied on to ignite the panels of the cupboard and set it on fire. The target-seeking propensity of an individual gob of gel from a 30 lb. bomb is probably higher than that of a single magnesium bomb owing to the sideways component of velocity produced by ejection from the case, and it is possible that the chance of such a gob starting a ' match ' fire may be as high as 0·4. The arrival of three such gobs of gel in a room would make the starting of a ' match ' fire almost certain, but a ' blaze ' could only be started with such a dispersion of the gel if all three gobs started primary fires together, and the chance of this happening is small. The 6 lb. of gel from a 30 lb. bomb may be distributed in such a way that small centres of combustion are initiated which are not large enough individually to grow even into " match " fires, but which are numerous enough and close enough together for mutual support to operate, and for a rapidly destructive fire to ensue.

On 18 October 1943, the first mortar-fired test with this bomb was made at Tondu. A full description of the set-up is given in Panel Report No. 69 in which the results of the first 38 tests are recorded ; most of these were concerned with the investigation of fuze behaviour and gel distribution. It was established that in operational use the bomb is most likely to function in the attic or in a room directly below this, and that the gel is scattered in fair-sized pieces, and very rarely dispersed explosively. At a later date, when the cellulose acetate filling had been adopted for this bomb, burning tests were carried out using the standard set of furniture, although the arrangement was modified somewhat to allow a greater concentration in that part of the room into which the bomb was fired. These results are recorded in Panel Report No. 91. In three out of the five cases in which the bombs functioned correctly, 'blaze' fires were obtained, 'flash-over' times of 5½, 6¾, and 6½ minutes being recorded. There was a feeling in the Panel that these results were only achieved because of the unusually high concentration of furniture in the path of the bomb. No other bombs were ever tried with such a high furniture concentration, and it is possible that, if they had, much shorter 'flash-over' times would have been obtained. The set-up used for these tests was probably never satisfactory; the furniture consisted of 'kindling' and 'bulk fuel' only, since it was designed originally to test the rate of fire growth with bombs which could only start fires by setting light to 'kindling'. For a bomb which is capable of producing a large number of centres of ignition it would seem only fair to provide all the possible sources of combustibility (such as curtains, pictures, radios, book-racks, coal-boxes, pipe-racks, books, magazines, toys, etc., etc.) which would be found in practice.

The 30 lb. petrol jet bomb

The work at Leeds had shown that the magnesium bomb is not an ideal fire raiser since so little of its heat is transferred sideways where it can be effective. It was natural to compare the short intense flames of burning magnesium with the larger but less intense, flames of hydro-carbons burning under natural conditions, and it was only a short step further to suggest that a horizontally directed jet flame might offer a very effective method of setting fire to combustible material. Weight for weight, most hydrocarbons have a greater heat output than magnesium, and a horizontally directed flame playing on the base of a vertical combustible surface is an ideal method of starting a fire; a vigorous horizontal flow of fresh air is induced and directed towards the target and the floor itself is dried out and heated up in preparation for spread of fire as soon as the primary fire has grown sufficiently.

In the first place a bomb fitted with a pre-heated jet and filled with about 2 lb. of butane was built at Leeds and gave quite promising results. Owing to the lack of availability of butane, however, this development was not followed up, and attention was directed to the use of petrol.

The first demonstration of this principle was given in the lower rooms of some condemned cottages in Leeds on 1 October 1942, and the results are given in Panel Report No. 9. The rooms were very small (about 12 feet by 10 feet) and the street door opened directly into them, opposite the staircase. The windows were boarded up and each room had a cupboard built in beside the chimney-breast and was furnished with a mock-up sideboard, table, and upholstered arm chair or small settee. In some there was also a small wooden or upholstered chair, but there were no curtains or carpets. The floorboards were distinctly damp. The ceilings were sound. A brick was removed from below the window to admit the petrol feed pipe.

Two tests were carried out using only a quart of petrol each time; this was the maximum amount it would be feasible to use in a 'match' bomb. In one case there was only superficial fire damage, and in the other a very slow fire was started, which died out of its own accord after 28 minutes. Two further tests were carried out using 1 gallon of petrol in each case. The fuel was injected at high pressure though a jet at the end of about 1 foot of flexible metal tubing so that the jet oscillated from side to side. A bomb containing this amount of petrol would be heavy enough to be classed as a 'blaze' bomb on the old system. In both cases, very rapidly destructive fires were caused.

These results were so promising that it was decided to build and test a number of mock-up bombs immediately. Each bomb consisted of a steel cylinder fitted with a central tube containing thermite, the burning of which raised the petrol to the desired temperature and pressure to form a jet of combustible vapour which was ignited to form a horizontal jet flame about 12 feet in length. The total weight of the bomb was about 30 lb. and it held 1 gallon of petrol which burned for about two minutes. Pressure development was aided by dissolving methane in the petrol but this meant that the bombs were always under pressure. At a later stage a mixture of shale spirit and alcohol was used with similar results.

One of these bombs was demonstrated along with others in the tests at Bridge Avenue, Hammersmith, which are described in Panel Report No. 17. Further tests were carried out with variations in the jet arrangement in the same row of houses on 23 March 1943, and these are described in Panel Report No. 17a. In each case the standard set of furniture was used, and some attempt was made to reproduce realistic atmosphere by covering the floor with linoleum and rugs, distributing books and magazines about the place, and hanging up black-out curtains at the bay windows. In every case rapidly destructive fires were produced; almost as soon as the jet formed, the whole room was so enveloped in flame that it was difficult to distinguish any incubation period prior to the 'flash-over,' and the fires built up steadily in a few minutes to a stage at which they were quite beyond stirrup pump control. In five minutes the rooms were gutted.

From this point the development of the bomb into a practical weapon proceeded with very high priority, and during this stage numerous tests were carried out at I.B. Cottage and in furnished houses at Rackham Street, North Kensington. The tests carried out up to April 1944 were all separately reported, but an excellent summary of them is given in Panel Report No. 66, from which the following extract is taken.

'The first three performance tests on the " J " bomb were made on experimental models at the Hammersmith site. Both single-jet and triple-jet models produced " blaze " fires.

Six tests were made on production models (single jet) in I.B. Cottage. In three of these where standard conditions were adopted, " blaze " fires resulted (8, 8½, and 9 minutes). In a fourth, the bomb was aimed at the wall in a corner of the room and most of the flames were directed upwards. Although some upholstery near the bomb became ignited, no continuing fire resulted. As a result of this test, a series of supplementary tests (described in Panel Report No. 60) was carried out to study the reflection of the bomb flame from the walls of the room when the bomb was placed in various positions.

Two more tests were made using salvaged bedroom furniture instead of the standard set. For the first the window was glazed and the door closed when the bomb was fired; there was then insufficient air to support combustion for long and no fire resulted.

After this, 16 tests were included in the first two series at Rackham Street with the bomb in various positions and the ventilation and furnishing of the room also varied. In these, no fire resulted in five cases, a " match " fire in five cases (31, 26½, 17, and 60 minutes respectively) and a " blaze " fire in six cases (5, 8½, 6, 5¾, and 4 minutes respectively).'

Some dropping trials with inert bombs were carried out at Leysdown, Isle of Sheppey, during October and November 1943, for the purpose of testing, functioning, penetration, cluster performance, and so on. The results showed that the structural damage caused by the bomb on entry had not so far been sufficiently allowed for in static tests. In many of these tests a large amount of 'kindling' was produced by the break-up of furniture, and ceiling laths were exposed where the plaster had been broken down. The same thing was noticed with the mortar-fired 30 lb. gel bombs at Tondu, and, although nothing was ever done to try and reproduce these effects, it was always realised that results in practice were bound to be slightly better than those of static tests.

From the tests carried out with the 'J' bomb it was possible to make a number of broad generalisations about its performance, and about the conditions necessary for the production of 'blaze' fires. Of these, first and foremost was the question of aeration. A large fire cannot develop and spread without an adequate supply of air; each 1 lb. of wood requires about 7½ lb. or 100 cubic feet of air for complete combustion. A primary fire in one piece of furniture which burns for 15 to 30 minutes is seldom short of air since fresh supplies are constantly being drawn into the room. A 'blaze' fire, on the other hand, exhausts the air much more quickly than it can be replaced by normal leakage into the room, and if the supply is to be kept up something must be done to break open windows or doors. In Panel

Report No. 57 it was shown that if the density of an attack with high explosive bombs is of the order of 100 tons per square mile, then 95 per cent. of the houses in the area suffer more than 50 per cent. of glass damage, and since each aircraft in the incendiary raids on Germany usually carried one 4,000 lb. blast bomb, it was thought that enough window damage would be caused to provide all the ventilation required.

The extent to which even a small slow-burning fire in a domestic room depends on air drawn in from outside is not often realised. In Panel Report No. 36 it was shown that when the oxygen content of air drops from 21 per cent. to about 15 per cent. by volume, flaming combustion cannot continue, although glowing combustion can be maintained at much lower concentrations. For example, in a room of 2,000 cubic feet capacity, the amount of air available for flaming combustion is only $\frac{6}{21}$ of $2{,}000 = 570$ cubic feet which weighs 3·6 lb.; this is only enough to burn $\frac{1}{2}$ lb. wood completely. Thus, even for the continued burning of quite a small fire, fresh air must be constantly drawn into the room. Glowing combustion may proceed for a considerable time in a tightly closed room, and the heat produced may raise the temperature of the remaining combustible material so near to the ignition point, that any sudden inrush of air caused by opening a window or door will cause an almost immediate 'flash-over.' Cases are on record where an apparently slow smouldering fire confined to one room of a building has suddenly burst into flame and consumed the whole building when windows or doors have been broken open.

The tests with the 'J' bomb also showed that even with the large heat output from the bomb itself (200,000 B.Th.U.) the ignition of one major piece of furniture was not sufficient to cause a 'blaze' fire except in a small room; it was necessary to set fire to all the 'kindling' in at least two major pieces of furniture or its equivalent during the active two minutes life of the bomb. The bomb was at its best in a well-furnished room with plenty of 'kindling' which could be ignited quickly so as to develop the heat required for firing the thicker timbers.

In Panel Reports Nos. 79 and 84, results were given of 'panel' tests carried out with various production models of the 30 lb. 'J' bomb. With this information and the experience of all the various tests already enumerated, it was possible to make an estimate of the S.I.E. of the bomb in Panel Report No. 60. The results were as follows:—

(*a*) For 'blaze' fires .. .. 0·48
(*b*) For 'match' fires .. .. 0·36

At a later date, the 'panel' tests were repeated using beech plywood, and other modifications of the bomb were also examined; the results are given in Panel Report No. 148.

The experimental 10 lb. petrol jet bomb

An objection which was continually urged against both the 30 lb. 'blaze' bombs was that no increase in incendiary efficiency could ever make up for the smaller numbers which an aircraft could carry. Although this point was hotly contested in some quarters, it was nevertheless felt that some attention should be given to the design of a 'match' bomb which would produce a horizontally directed flame. This particular work was on a very low priority during the war, but its possibilities should not be overlooked.

An experimental bomb was produced by the Ballistics Branch of A.R.D. and tried at I.B. Cottage on 17 February 1944. It contained a quart of petrol and could have been developed into a 10 lb. size bomb. The heating was provided by the burning of coated cordite and this was found to be very effective. A 9-foot long flame was produced which burned for about 2 minutes In the test the bomb was placed with the jet 6 feet from the corner group of furniture normally used as the target. The bomb set fire initially to more furniture than other small bombs but the duration of the bomb flame was too short for it to establish a larger primary fire than usual. Consequently the final result was only a normal 'match' fire which 'flashed-over' in $18\frac{1}{4}$ minutes (*see* Panel Report No. 73). An approximate assessment of the S.I.E. of a bomb with a 9-foot flame in the standard German apartment gave a value of over 0·8 compared with the value of 0·27 for the 4 lb. magnesium bomb (*see* Panel Report No. 26a); this difference more than counteracts the difference in weight.

The 22 lb. naphthalene-filled jet bomb

The 30 lb. liquid-filled jet bomb was complicated to manufacture and it had a low charge-weight ratio. Several attempts were therefore made to substitute a solid hydrocarbon or other filling for the liquid fillings which had been used. The A.R.D. at Tondu produced an experimental bomb containing a solid pyrotechnic mixture which gave good results in tests at I.B. Cottage and Rackham Street, but the development was not proceeded with. M.D.1 Ministry of Supply, produced a naphthalene-filled bomb which had greater promise since, although it had a higher B.Th.U. content than the liquid-filled bomb, a much lighter case could be used, and the weight was reduced first to 22 lb. and later to 20 lb. A pyrotechnic heater mixture dispersed through the filling was used to vaporise the naphthalene and eject it from the jet. The flame was not quite as long as that produced by the petrol bomb, but it was much more intense and had a greater sideways range. In tests at I.B. Cottage on 25 November 1943, and 15 December 1943, this bomb caused 'blaze' fires (10½, and 8 minutes) and it was considered that the bomb was equal in performance to the 30 lb. 'J.' 'Panel' tests with various adaptations of this bomb are described in Panel Report No. 147.

An interesting development from the testing point of view was the incorporation into this bomb of a window-breaking charge. In favourable circumstances, this bomb, like the 30 lb. 'J', was capable of starting very rapid fires which required a large volume of air, and in a new design like this it was felt that it would be wiser to incorporate a small explosive charge that would make certain that the windows were blown out, rather than rely on the effect of 4,000 lb. blast bombs dropped in the neighbourhood.

Some tests were carried out at Rackham Street, North Kensington, on 18 October 1944, in which a direct comparison was made in rooms furnished with the standard set of furniture, of the 30 lb. 'J' and the 22 lb. 'J' fitted with a window-breaker which operated after about one minute. The 22 lb. 'J' gave the best performance in a 'favourable' position and also in two 'less favourable' positions, giving fires which reached the 'flash-over' in 2¾, 3, and 4 minutes respectively. The 30 lb. 'J' bomb tested in two positions also caused large fires, but as it did not break the windows the fires developed rather slowly and the 'flash-over' was not reached until after 11 and 8 minutes respectively. The importance of ventilation control in any method of testing which involves the growth of rapid fires was thus amply demonstrated.

Starting fires in unoccupied German attics

It has been described how the United States had developed the M.69 bomb for starting fires in German attics. The early experiments with half-attic structures at the Standard Oil Development Laboratories at Bayway, New Jersey, were supplemented in the spring of 1943 with tests on full scale structures of two types—the Rhineland type with slate-on-sheathing roofs, and the Central German type with tile-on-batten roofs. Full details of these tests are given in S.O.D. Coy.'s Reports Nos. P.D.N. 1201 (15 April 1943) and P.D.N. 3800 (30 July 1945).

The timber used for these structures was mostly Southern Loblolly pine which was force-dried to a moisture content of 7–12 per cent. before erection. With both types of roof structure, a number of potentially destructive fires were produced by the M.69 bomb functioning in the attic, although the need for conserving the buildings for future tests made it necessary to stop the fires from reaching the destructive stage. It was found that the Rhineland structure was easier to set afire than the Central German, owing to the presence of the extensive boarded roof surfaces which are so favourable for spread of flame and the establishment of mutual support between the floor and the roof along the eaves line.

While these tests were proceeding at Bayway, the N.D.R.C. and C.W.S. had decided to erect a number of German houses of both types, as well as some Japanese houses, at Dugway Proving Ground on the Great Salt Lake desert in Utah, so that full-scale dropping tests could be carried out, and the efficiency of a number of incendiary weapons compared under realistic conditions. This scheme was pressed forward with amazing rapidity and the first dropping tests were carried out in May 1943, with results highly favourable to the M.69 bomb.

In this country we were being pressed to use the M.69 bomb against Germany, although it did not satisfy an Air Staff requirement that small incendiary bombs must be capable of penetrating to the floor below the attic. On the basis of the tests at Bayway, however, it was claimed that the M.69 would cause destructive fires even in attics on account of its eaves-seeking device, and that such fires would spread downwards and involve the whole house. All the experimental work in this country up to that time had produced the firm impression that, while such a result might be possible in the Rhineland type of structure, it was hardly likely to occur in the much more common Central German type where the only combustible parts of the sloping roof were the traditionally heavy rafters and cross battens—well above the size in which self-propagation of flame is possible.

Some tests had been carried out at Bridge Avenue, Hammersmith, on 8 March 1943, which gave support to this latter view. In the first test the gel was fired into the eaves of an unboarded attic, the roof being of the common slate-on-batten English type. The sizes of all the timbers were appreciably smaller than those which were assumed to be common in Germany, though, of course, there was no boarded floor or roof to help. As long as the gel was burning, surface flaming was maintained over several square yards of the joists, rafters, and battens, but when the gel was consumed the fire died down and was easily extinguished with a little water from a stirrup pump after a period of 15 minutes. Some slates which had been blitzed off on the far side of the attic from where the gel was burning were not replaced as it was felt that they would represent the hole made by the bomb on entry. It was noticed that a large amount of heat escaped through this hole and was not utilised in raising the general temperature level in the attic. The primary fire was not large enough under these conditions to produce a ' flash-over.' In the second test a wooden partition was erected between the floor and the ridge so as to confine the heat and provide a large heat absorbing combustible surface opposite to the fire. The result was what afterwards became to be recognised as a typical ' match ' fire. The gel burned for about 20 minutes, but by this time the fire had not only climbed up to the ridge but had preheated the partition to its ignition point, and a ' flash-over ' followed.

It was evident from a consideration of these preliminary tests that much more testing would be necessary in actual German-type attics, before the M.69 could be accepted for operational use. If had been intended originally to erect such an attic on the extension walls of I.B. Cottage, and plans were prepared for this purpose by the B.R.S. in consultation with R.E.8 and R.R.L. who had made a great number of bomb penetration tests in German-type roofs. On 16 April 1943, however, it was decided to defer construction pending receipt of information on some proposed modifications of the M.69 bomb and also concerning the test structures then being erected at Dugway.

At the beginning of June 1943 M.A.P. asked for the provision of a German attic in which to test the 30 lb. 'J ' bomb and it was decided to erect this at B.R.S. on a separate site away from I.B. Cottage. The original plans were modified accordingly and fresh ones prepared by R.E.8 for a single-storeyed building to carry the attic. A complete description of it is given in Panel Report No. 61. It was known as Q.1.

By the end of the summer of 1943 the successful results with the M.69 bomb at Dugway had created such a stir in both countries, that it was decided to extend the British testing programme considerably, and in November, two pairs of semi-detached houses were built, one pair having a common attic (Q.2) twice the size of Q.1, and the other having separate attics (Q.3 and Q.4) each equal to Q.1. The timber used in Q.1 was Douglas fir, kiln-dried and conditioned to 17 per cent. moisture content. That used in Q.2, 3, and 4 was a mixed consignment of old, seasoned material which did not require special conditioning.

The M.69 bombs were fired so as to eject the sock of gel into the eaves in the middle of one of the ' bays ' between two adjacent rafters. The actual eaves line consisted of two courses of 4½-inch brickwork which occupied the space between the top of the 9-inch walls at floor level, and the tiling battens. Consequently the gel, on ejection, came to rest mainly on the brickwork instead of on either floorboards or battens, and in order that the bomb should not be at any disadvantage on this account it was decided (after the first two tests) to fix a skirting board in each bay in front of the brick eaves filling. It was also found that the tail cup of the bomb which was ejected with the gel on firing broke the tiles just above the eaves and allowed much of the flame and heat from the gel to escape. To prevent this, and so give the bomb every advantage, sandbags were placed on the outside of the roof in all subsequent tests, over the area where the tail cap was likely to hit the tiles.

The first three tests with the M.69 bomb were made in attic Q.1 on 2 December 1943. The bombs were placed 8–10 feet from the eaves filling and aimed at three different bays on the east side of the roof (furthest from the stair well). In none of these cases did the gel produce a self-supporting fire. Most of the gel was duly deposited within the area intended and appeared to burn normally, but it did not set fire to more than two or three of the battens, and the floor became only slightly charred. Once the gel was exhausted, the flames on the woodwork diminished, and after 15 minutes there was little or no fire left. The introduction of a skirting board in the third test assisted the gel and caused more widespread flaming at first, but the final result was the same.

Next a British 4 lb. Mark IV magnesium bomb was placed on the floorboards in another bay, 1 foot from the skirting board. The effect was much the same as in the tests with the M.69 and all flaming ceased after 12 minutes.

Finally, a 30 lb. 'J' bomb was placed 11 feet away from one of the bays previously used, where there was little fire damage. The flames from the bomb jet (which was in action for $3\frac{1}{2}$ minutes) enveloped the whole of the east side of the roof and set fire, superficially, to much of the woodwork, but as soon as the jet ceased to function all the flames went out.

The above tests were carried out during a period of cold, damp weather. In view of the complete failure to set fire to the roof timbers it was decided to examine their moisture content; although they had been conditioned to 17 per cent. before erection, and had been protected from rain throughout, the building itself was unheated and the tiles, no doubt, were wet. The results of these determinations showed that the moisture content of the roof timbers ranged from $17\frac{1}{2}$ to 20 per cent. with an average of 19 per cent., and that of the floor boards was about 16 per cent. Before proceeding with any more tests, therefore, it was decided to dry out all the buildings thoroughly. The damaged areas of Q.1 were repaired and braziers installed in all the attics.

After about a fortnight's drying it was found that although very little change had been produced in the floor boards, a reduction of about 4 per cent. had been achieved in the roof timbers. Three more M.69 tests were therefore carried out, but although the woodwork appeared to be burning rather more strongly during the life of the gel than in the previous tests, the final result was the same and no continuing fires were produced.

There was thus an apparent disparity between these results and those reported from Dugway. The full details of the Dugway tests were not, however, available in this country at the time, and it was not until a visit had been paid by a member of the B.R.S. staff to Dugway in March 1945 that it was realised that the only fast fires started in the German attics there were those in the boarded attics of the Rhineland type, which were not comparable with those at Garston. At the time it was thought that the two most likely factors which might account for the difference in the results were

(*a*) The construction of the test attics.

(*b*) The moisture content of the timber and tiles as affected by the atmospheric conditions prevailing before and at the time of the tests.

As regards (*a*), N.D.R.C. representatives who witnessed most of the earlier tests agreed that the timber construction in the Q attics was essentially the same as in the Dugway buildings, although they pointed out that in Q.1 the floor area was considerably smaller, and that this might have some effect on the rate of growth of the fire to destruction if appreciable areas of the roof took fire. In the actual tests, however, this contingency did not arise although provision was made against it by making the attic Q.2 (which was then being built) double the area of the others.

As regards (*b*) the timber in the Dugway attics was stated to have been conditioned to 14 per cent. whereas most of the British tests had been carried out at higher moisture contents than this. At the time of the year that the U.S. tests were done, however, the Utah desert is one of the driest places on earth (*see* meteorological figures for Salt Lake City in Panel Report No. 59a) and the average equilibrium moisture content of timber is nearer 6 per cent. than 14 per cent. The temperature was also much higher than that prevailing in this country in December, and although there were frequent falls of heavy rain, the sun soon evaporated all the moisture from the tiles and dried them out again. It is difficult to see how the surface moisture content of any of the timber at Dugway could ever have been much above 6 per cent.

An attempt was made therefore to dry out the Q attic still further, and at the same time some pilot tests were initiated using eaves section which could be easily dried out. Each section represented one of the ' bays ' in the attic to a vertical height of 6 feet. The floor was boarded as in the Q building but not pugged. The sides were left open, and instead of a brickwork eaves filling, plasterboard was used. One section was conditioned to 18 per cent. moisture content, and the other to 12 per cent. moisture content before erection, and the tests were carried out as quickly as possible afterwards in a large room free from draughts, and ventilated by means of extractor fans.

As was expected, no continuing fire was produced with the 18 per cent. section. The other behaved quite differently ; within two minutes flames reached the top of the structure and four floor boards began to burn. Later, fire became firmly established in the battens near the base and from thence gradually spread to other battens until most of them were burning steadily. At 5–6 minutes the inner faces of the rafters and posts took fire, but the flames on the posts later went out. The fire continued to burn steadily after most of the gel had burned away and at 19–20 minutes the battens began to collapse, and the test was soon after discontinued. It looked as though there would have been a good chance of such a fire, if it had been in part of a complete attic, being a destructive one.

In the meantime, braziers had been kept burning in Q.1 and Q.3 and the charred woodwork had been carefully wire-brushed and scraped to expose fresh surfaces. The weather during this period remained cold and very damp, but by 17 January 1944 meter readings showed that the moisture content of the timbers had been reduced to 11–13 per cent. An oven drying test on a batten gave a value of 11·3 per cent. On 20 January thereafter a further test was carried out with an M.69 bomb in Q.3.

As soon as the bomb was fired, flames from the gel spread over the first six or seven battens and the wood began to crackle. The skirting board and the floor boards took fire, and the fire continued to burn steadily for the first 9 minutes. At this stage it became apparent that some of the battens were beginning to burn independently and the fire increased somewhat in volume and intensity. There was no large increase, however, until 24 minutes and little lateral spreading. At 25½ minutes there was a ' flash-over ' involving all the timbers in the bay up to the purlin and several of the floor boards beneath this area. The flames then died down somewhat, but a second seat of fire had become established over the purlins.

During the next half-hour the fire fluctuated but gradually increased and eventually reached the ridge 70 minutes after the start. At no time was the heat sufficient to make the attic untenable. As the fire approached the ridge, tiles and battens began to fall in ; this did not materially increase the fire but, rather, allowed the heat to escape. Only about four battens at the top of the west slope of the roof became affected and after 80 minutes it was apparent that there would be little further spread and the fire was extinguished with a hose.

On the same day a test was carried out with the 30 lb. ' J ' bomb in Q.1, the jet of the bomb being placed 10 feet from the eaves line. The flames from the bomb enveloped the whole of one side of the roof, and very soon the roof and floor timbers took fire superficially. Most of the flames died out, however, when the bomb was exhausted and only a few battens here and there remained alight. The fire was left undisturbed for 40 minutes, but little further change took place. A little smouldering continued in angles where adjacent timber surfaces afforded mutual support to the burning, but a little water from a stirrup pump was sufficient to extinguish these places.

Evidently neither of the bombs tried was capable of producing a rapidly destructive fire in an attic similar to those used in the tests even when the moisture content of the timber was as low as 12 per cent.

One factor in these last two tests had assumed greater importance than was at first realised, namely the wetness of the tiles, coupled with the high atmospheric humidity and low temperature at the time of the test. Tests on tiles removed from Q.2 and Q.4 gave values of 18·9 per cent. and 20·1 per cent. respectively. There were 483 such tiles on the East side of Q.3 roof which therefore contained about 440 lb. of water altogether. The moisture in the tiles might be expected to retard the fire not only by absorbing heat but also by raising the moisture content of the surface layer of the battens in contact with the tiles. In one test, an actual film of water was observed on the underside of the tiles; this may have been due to condensation from the flames on a cold, saturated surface, or to exudation from the tiles themselves, but whatever the cause, the effect on the battens which were in contact would be the same.

After making the allowance for the wetness of the tiles it was still felt that the tests had justified the prediction of the Panel, based on fundamental considerations of flame propagation in relation to timber size and the effect of mutual support, that it was not generally feasible to produce continuing fires in unoccupied German attics. This conclusion was approved at a Panel Meeting on 3 March 1944 and was concurred in by the U.S. representatives present: as a consequence, the M.69 bomb was never used on Germany.

On 2 June 1944, after four months of unusually dry weather terminating in a spell of hot weather, the tests were repeated, but with similar results. The timbers ignited fairly readily but did not continue to burn for long after the bomb was exhausted. Details of these tests are given in Panel Report No. 78 and again the conclusion was reached that none of the bombs tested was capable of producing destructive fires in unoccupied German attics, assuming these to contain no lighter timbers than the 2½ inches by 1½ inches, tiling battens which were used at Garston.

The visit to Dugway mentioned previously was referred to in Appendix B of Panel Report No. 128. It was pointed out that the attics at B.R.S. were of the tile-on-batten or Central German type, and as such were only comparable with similar attics at Dugway. On the Dugway classification, the slow continuing fire produced in Q.3 on 20 January with an M.69 bomb would be a 'B' fire. At Dugway the results with this type of roof were not strikingly different. Only three fires are recorded—two of which were class 'A.' One at least of these is known to have occurred in a vulnerable situation not provided by Q.3, namely, in a small space enclosed between the wall of the stair well (partly of wood) and the eaves. The location of the other 'A' fire is not certain. The only photograph of a fire in this type of attic (No. 57 in T.D.M.R. No. 713) illustrates a (presumably typical) 'B' fire, remarkably like the fire in Q.3. Five major fires, however, are recorded as having been produced in the boarded Rhineland attics, and it is only natural that such a target would be more favourable than a tile-on-batten roof, since it provides such a large, continuous area of woodwork, and such excellent opportunities for mutual support between the floor and the sloping roof boards.

The effect of moisture on the burning of wood

The study of fire-raising in German attics emphasised the need for controlled wood moisture content in any tests involving the burning of wood. A good deal of consideration was given to this problem at different times, and the story is now fairly complete from a practical point of view, although there is still room for further investigation.

In Panel Report No. 52 it was pointed out that the average gross calorific value of wood at zero moisture content was approximately 9,000 B.Th.U. per lb. Allowing for the heat required to raise the wood to its burning temperature (say 270° C.) and for the latent heat of the water formed during combustion, the heat available at 270° is about 8,300 B.Th.U. per lb. The quantity of water which this amount of heat will vaporise and raise to 270° C. is about 6½ lb. which corresponds to a moisture content of 650 per cent. As the wettest wood can never approach this moisture content, then theoretically wood at any moisture content is capable of burning and liberating excess heat.

This argument does not take into account the fact that, when wood burns, a large proportion of the heat liberated is dissipated by radiation and convection. It is only a small fraction that is available for heating up the wood, evaporating the moisture, and maintaining combustion. This fraction varies widely and is dependent on the rate of combustion and the external conditions under which the wood is burned. Obviously if wood is burned under conditions in which no heat is lost to the surroundings as in a furnace, the wettest wood will burn and liberate heat ; on the other hand, as we have already seen, a single thick piece of wood will not continue to burn even at very low moisture contents if conditions are such that the heat is dissipated faster than it is liberated. Thus there is no single critical moisture content at which wood will not burn ; it varies with the dimensions and disposition of the wood, and the external conditions.

This is illustrated by the following results of strip burning tests on samples of Baltic redwood and Douglas fir 24 inches long and of cross section varying from $\frac{1}{4}$ inch square to $\frac{1}{2}$ inch square, which were conditioned to moisture contents of 0, 7, 11, 14 and 19 per cent. Each sample was suspended vertically and the lower end ignited with a Bunsen flame ; a note was made of whether or not the burning continued to the top of the stick. The results are given in Table No. 3.

Table No. 3

Species and Size.		Number of sticks out of three which continued to burn. Moisture content, per cent.				
		0	7	11	14	19
Baltic redwood	$\frac{1}{4}$ in.	3	3	3	3	3
	$\frac{3}{8}$ in.	3	3	2	1	1
	$\frac{1}{2}$ in.	3	1	1	0	0
Douglas fir	$\frac{1}{4}$ in.	3	3	3	3	1
	$\frac{3}{8}$ in.	3	2	2	1	0
	$\frac{1}{2}$ in.	3	0	0	0	0

With the $\frac{1}{4}$-inch sticks it is obvious that moisture content has very little effect on the continuance of burning, while with the $\frac{1}{2}$-inch sticks the flame is almost certain to die out unless the moisture content is much lower than is usually found in practice.

This raises the further question—' what is the moisture content of wood in practice ? ' A living tree contains moisture derived from the soil (sap moisture) and moisture derived from the atmosphere. When the tree is cut and the sap moisture dried out the moisture from the atmosphere still remains and reaches an equilibrium value depending on the partial pressure of the water vapour in the air with which the wood is in contact. This means that the relative humidity and temperature of the atmosphere are the controlling factors. This relationship was determined from experiments with shavings of six different species of wood and is only an average one, but the differences between species are not very large.

Changes in equilibrium moisture content, however, always lag behind changes in relative humidity, and the actual moisture content of a piece of wood at any time is a function, among other things, of the direction in which the change has taken place, the diffusivity of the wood for moisture, and the specific surface. Thin shavings of a high diffusivity wood like Sitka spruce respond so quickly to changes in relative humidity that they can almost be used as hygrometers ; on the other hand, heavy oak beams taken from old London buildings have still been found to contain sap moisture after hundreds of years. Interesting data on this aspect of the problem is given in Part 2 of I.E.P. Report No. 6.

It is obvious that the task of estimating the moisture content of, for example, a window frame in Germany in December, is not just the simple one of looking up meteorological records and then reading off the corresponding moisture content from the equilibrium curve. The diurnal variation of relative humidity alone is considerable and must be taken into account. A value of 60 per cent. at midday can change to saturation at midnight producing a corresponding change in the moisture content of the surface layers from 11 to 31 per cent. However, while the moisture content of this surface layer is of great importance, as will be seen, at the start of a fire, it is the bulk moisture content which becomes more important as the fire grows and spreads, and the variation in this is very much smaller.

The problem of interior woodwork is even more complicated, since the relative humidity inside is dependent so largely on interior heating. Reference to any standard psychrometric chart shows that a rise in temperature of a given mass of moist air by 10° F. lowers the relative humidity by 20–25 per cent. and this is equivalent to a lowering of the equilibrium wood moisture content of approximately 5 per cent. In summer, when doors and windows are left open, the inside atmospheric conditions tend to be similar to those outside, but even under the best system of ventilation the inside temperature is usually a few degrees higher than the outside.

The importance of this aspect of moisture control again became apparent in the summer of 1944 when the first attempts were made in this country to start fires in simulated Japanese houses. The Japanese problem was fundamentally different from the German one in several respects. Firstly, Japan has a monsoon type of climate and the seasonal changes of humidity are the reverse of those in this country and in Germany, *i.e.* the winter is a time of low humidity and the summer a time of high humidity. Secondly, there is very little furniture in the house and the only easily combustible objects are the various partitions and shutters and the hung ceiling, all of which are of light woodwork. The high summer humidity produces a high moisture content in this woodwork, but since it is of light construction, the effect on the starting of fires is not likely to be noticeable although the rate of growth of fire to the destructive stage may be affected.

When the M.69 dropping trials were carried out at Dugway (May–June 1943), the moisture content of the Japanese houses ranged from 3·1 per cent. to 16·4 per cent. which makes it probable that the light structural members and thin woodwork generally were in the 3–11 per cent. range. Under these circumstances very rapidly destructive fires were obtained. Preliminary tests in this country carried out in October 1944, before the buildings had dried out, and when the moisture content varied from 15–20 per cent., showed that it was difficult to start fires at all with any of the ' match ' bombs. Most experienced observers were prepared for destructive fires in these houses when they had been dried out to some reasonable moisture content—say 12–14 per cent.—but it was difficult to imagine how they could ever be as fast as those at Dugway. It was found eventually that several other factors contributed to this discrepancy and these are discussed more fully later, but the difference in moisture content was certainly one of them.

As a result of an incident which occurred during the dropping trials at Dugway, it was maintained in some quarters that moisture content had no effect on the starting of fires there. A destructive fire had been started in a room of one of the Japanese houses, but in order to save the rest of the building for further tests and to be ready for the next bombing run, the fire was extinguished with water and the room rapidly damped down. Within a short time a further cluster of bombs was dropped, and one bomb fell into the same room and within a few minutes the whole place was ablaze again.

Now a little consideration will show that, under these circumstances, the surprising thing is not that a large fire was re-started so quickly, but that it took another bomb to re-start it. The first thing a fireman has to learn is that once the flames have been extinguished, the next most important requirement is to cool all the woodwork down so far below the ignition point that there is no further possibility of its bursting into flame again. This requires an enormous amount of water when used in the traditional way, since most of it drains off with very little elevation in temperature. The water on the wood naturally cools the surface first, and then the flow of heat is from the interior outwards. In a well-established fire most of the moisture in the wood has been evaporated, and the inside temperature may well be 500° C. or more above the surface temperature ; the flow of heat to the surface may, therefore, evaporate all the cooling water and raise the charcoal surface once again to the self-ignition point unless fresh water is continually applied for a long time. The only way of employing water efficiently for cooling purposes is to make use of its latent heat of vaporisation by turning it into steam, and this is rarely done to any extent in practice.

In some experiments at Edgewood it was found that charred wood taken from a well-established and freely burning fire which had been extinguished and well wetted down, still only had a moisture content of 5 per cent. despite the fact that it was picked out of a heap of completely wet charcoal ; the dryness of the interior more than made up for the film of water on the surface.

The moisture content of wood in houses in Japan in the summer

In this country it was thought that 16–18 per cent. was a close approximation to wood moisture content conditions in Japan in the summer ; it was suggested that it should be even higher than this to allow for the moisture given off during the night from the large number of people known to occupy one room. In the U.S., the representatives of the Standard Oil Development Co. considered that Dugway was a fair approximation since they allowed for a probable 5–10° F. excess of internal over external temperature even in the summer time. This aspect was discussed at length in their report P.D.N.3150 (December 1944).

The selection of the most appropriate moisture content was decided after an actual investigation into wood moisture conditions in inhabited houses in Key West, Florida (*see* I.E.P. Report No. 6). This location was chosen because the climate of Key West was found to be a good approximation during the months of December, January, and February, to that of Tokyo during the summer months of June, July, and August, when it was expected that conditions would be most difficult, and incendiary bombing would probably reach its climax. Sample boards of Sitka spruce (chosen to represent Japanese hinoki and sugi), ¼ inch and ¾ inch thick, were placed on the verandahs, in the bedrooms, and in the attics of a number of houses occupied by large families. In each of these houses Japanese ventilation procedure was reproduced during the tests, *i.e.* doors and windows were kept open during the day, but were shut up closely at night. The samples were weighed twice daily at times which gave the maximum and minimum values of the diurnal weight variation, and mean values were calculated. Two tests were carried out, one in which the final moisture content values were approached from above, and the other in which they were approached from below. The means of these values for each location were used to decide the most probable moisture contents. These were found to be :—

(*a*) On the verandah (*i.e.* exposed to the outside air temperature and relative humidity, but not actually in the sun) .. 17½ per cent.
(*b*) In the inside rooms .. .. 15 per cent.
(*c*) In the attic spaces .. .. 13 per cent.

If it is considered that the drying out of wood in the dry Japanese winter produces a condition equivalent to approaching equilibrium from below, then 13½ per cent. might be adopted rather than 15 per cent. It was found that the diurnal variations were 2–3 per cent. for wood directly exposed to the atmosphere, 1 per cent. for wood in attic spaces, and less than 1 per cent. for wood in inhabited rooms.

In considering the Japanese problem it was felt in some quarters that atmospheric humidity itself, apart from its effect on moisture content, would have an appreciable effect on burning, especially in the early stages. Some experiments were therefore carried out to test this point which are described in Panel Report No. 112.

Matched samples of Baltic redwood, Douglas fir and Western red cedar, ⅜ inch by ⅜ inch by 2 feet long, were conditioned to constant weight at relative humidities of 30 per cent., 60 per cent., and 90 per cent., and at a temperature of 25° C. Samples conditioned at each humidity were then tested at the three different humidities by means of the strip burning test, which consisted of suspending the sample vertically and igniting the lower end with a standard Bunsen burner flame for a period of 1 minute. The samples were transferred individually in glass tubes and tested immediately on removal from the tube. The results are given in Table No. 4 which shows the number of samples out of a total of three (two in the case of Baltic redwood) which burned out completely after removal of the igniting flame.

Table No. 4

Species.	Samples conditioned at R.H. of	Number of samples out of three tested which burned completely. (Two samples only tested in the case of Baltic redwood.) Tested under conditions of 22–25 per cent. R.H.	60 per cent. R.H.	90 per cent. R.H.
Western red cedar ..	30 per cent.	3	3	3
	60 per cent.	3	2	0
	90 per cent.	0	0	0
Douglas fir	30 per cent.	3	3	3
	60 per cent.	2	2	2
	90 per cent.	2	—	0
Baltic redwood ..	30 per cent.	2	2	2
	60 per cent.	2	2	2
	90 per cent.	2	1	0

These results indicate that humidity of the surrounding air may have some influence on the burning of wood irrespective of its effect on the moisture content. The effect is most pronounced where continuity of burning is in the balance, and in such cases air humidity may decide whether flaming will continue or not. The quantitative significance of the effect is difficult to assess, but from these limited tests it will appear to be appreciable and at least as significant as the effect of species within the range tested. However, under the unstable conditions existing when flaming just may or may not proceed the effect of any factor influencing burning one way or the other may decide the issue irrespective of its quantitative effect.

Much more experimental work is required before a satisfactory explanation of the effect can be produced. The amount of water vapour in the air is so small (only 1 per cent. by weight at 70° F. and 70 per cent. R.H.) that a change in relative humidity can hardly affect either the heat capacity or the oxygen content significantly. It is possible that moisture vapour affects both the conductivity of the air and the physical characteristics of the flame to such an extent that the rate of combustion is modified.

The magnesium powder bomb

On 4 December 1944, a demonstration was given at the Maryland Research Laboratory by a member of the U.K. Inter Services Research Bureau of a new and apparently extremely effective method of fire-raising.

In the first place a bag containing 1 lb. of magnesium powder was ignited and dispersed by the firing of a small gunpowder charge inside a wooden box, 3 ft. cube, with one side held slightly ajar to allow access of air. Immediately, all the inside surfaces of the box became inflamed, and in less than a minute the whole box was well alight and soon burned to destruction.

Following this, 25 lb. of magnesium powder was ignited and dispersed in a similar way inside a wooden hut 10 ft. by 10 ft. by 10 ft. with a small opening in one side, and a door on the opposite side which was left half open. Some of the powder was consumed in a flash burn and the force of the explosion blew out one side of the hut, but this side nevertheless continued to burn to destruction although it lay horizontally on the field. The remaining interior surfaces were inflamed in a few seconds, and in less than five minutes the whole building was destroyed. It was noticed that a large amount of magnesium had not been dispersed and lay burning in a flat heap on the floor where it contributed little to the progress of the fire ; evidently less than 25 lb. would have been sufficient.

Further demonstrations of this principle of fire-raising were given in both the U.S. and the U.K. in the ensuing months. It was intended originally for development as a sabotage weapon, but the advantages of an airborne weapon working on this principle were also realised. It was decided to try and make a bomb containing about 6–8 lb. of magnesium, and the pressed steel case of the 20 lb. ' J ' bomb was considered ideal for the purpose. A mock-up bomb was soon produced weighing in all 18 lb., and was fired statically in the Japanese houses at B.R.S. on two occasions, when ' flash-over ' times of 53 and 90 seconds were obtained. In a further test with all the screens removed, a ' match ' fire only resulted, the ' flash-over ' time being 12½ minutes. When fired in the German attic (Q.3) it started only a minor fire which died out after 5 minutes.

In these tests, with the bomb fired statically, it was impossible to reproduce the sort of distribution which is produced by the ejection and dispersal of the powder from the bomb while it is still in flight. The same difficulty had been experienced with the 30 lb. gel bomb which also ejects its contents while in flight. It was decided, therefore, to erect a Japanese room, similar to the one at Edgewood, inside the test house at Tondu, so that bombs could be fired into it from a mortar and the correct powder distribution obtained.

Unfortunately further differences were introduced into the construction of this room just at the time that the report emphasising the importance of these differences was being compiled. Consequently it is impossible to compare the results directly with any obtained at any of the other sites—Dugway, Garston or Edgewood. However, extremely rapid fires were started and it is reasonable to suppose that similar fires would have been obtained under mortar-firing conditions at any of the other sites.

At the request of the Panel, some experimental work was carried out at Leeds University which helped to elucidate the mechanism of the action of dispersed magnesium powder in starting fires. This work is described in Panel Report No. 149. At first a 2-feet cube box was used and the following observations were quickly made :—

(*a*) The amount of magnesium required for a destructive fire was independent of the thickness of the wood used, so that it must be a phenomenon of surface ignition only. This had already been inferred from the rapidity of the action.

(*b*) Larger quantities of magnesium powder were required if it was spread on an incombustible instead of a wooden floor. This suggested that the distillation of combustible volatiles from the surface of the wood played an important part in the action.

(*c*) Very much larger quantities of magnesium powder were required if it was spread uniformly over the floor but not in contact with the side walls (leaving a gap of 2 inches), than if it was allowed to reach the side walls ; if the powder was distributed along the edges and in the corners—and this was found to be the most usual distribution in the mortar-firing tests at Tondu—quite small amounts were found to suffice. This clearly indicated that mutual support between the floor and the sides, and between one side and another, played an important part in the rapidity of build-up of the fire.

(*d*) The amount of magnesium required was independent of the particle size.

(*e*) The amount of magnesium required decreased with decreasing moisture content in the timber.

The experiments were then extended to larger boxes, and it was found that as the size of the box increased, the amount of magnesium required to produce a destructive fire increased very much more than in proportion, the relation between the two being given by the equations

$$W = 0{\cdot}3\ S^{2\cdot4} \text{ for an even floor distribution}$$

$$\text{and } W = 0{\cdot}06\ S^{2\cdot4} \text{ for an edge distribution}$$

where W = weight of magnesium in lb. and S the size of the box in inches. The wood used in the tests had a moisture content of 17 per cent.

It was concluded from this that the maximum size of box which could be fired by the magnesium in an 18 lb. bomb was about 9 feet cube. The bomb is essentially, therefore, a small target weapon.

It is now possible to account for the rapid action of this method of fire raising in the targets in which it has been tried, and to give some general idea of its limitations. The magnesium powder is in intimate contact with the combustible objects on which it is deposited, and as it burns at such a high temperature the point is quickly reached at which the surface layers begin to distil volatile gases which force their way through the thin layer of burning magnesium and are ignited thereby. With a pool of burning magnesium as from a 4 lb. bomb, this action only takes place round the edge of the pool. At the same time, the high radiation flux raises the temperature of neighbouring combustible surfaces to the ignition point—heat transfer at these intensities being more efficient than at lower intensities. If the various objects thus ignited were isolated from one another this superficial burning would be of short duration unless the objects were made of very light ' kindling '. If, however, there are a large number of adjacent surfaces all in the same condition, the fires support each other and the general level of temperature is raised to such a point that burning continues after the burning magnesium is exhausted. The success of this bomb depends therefore on

(a) The high radiation intensity produced by burning a large amount of magnesium in a short time in a confined space,

(b) The fact that a large number of neighbouring combustible surfaces are capable of being attacked at the same time so that the fires thus started can become mutually supporting.

As we have seen, the efficiency of this method of fire-raising increases rapidly with decrease in target size, and increase in the proportion of combustible surfaces present.

It is interesting to compare the magnesium powder bomb with the other main types. ' Match ' bombs, like the British 4 lb. magnesium bomb or the American M.69 oil bomb, liberate their heat slowly and start fires by igniting ' kindling ' which is capable of self-propagation of flame once it is ignited. The 30 lb. ' J ' bomb was designed to liberate a greater total amount of heat, but chiefly to liberate it at a much higher rate ; its success as a ' blaze ' fire raiser depends on the fact that it is capable of igniting all the ' kindling ' within its range so that mutual support between adjacent fires enables them to become independent of the bomb during its short active life. If the supply of ' kindling ' is deficient the bomb only acts as a ' match ' fire raiser. The 20 lb. ' J ' bomb has an even higher radiation intensity, and is consequently even more dependent on the presence of a large amount of ' kindling ' in its effective range. In the magnesium powder bomb this tendency to increase the radiation flux and rely on the presence of numerous adjacent combustible surfaces to establish mutual support, has almost reached its limit, since all the heat is liberated at these surfaces in such a very short time.

As long as the target being attacked is a small unit with a high degree of combustibility—as it is in the average furnished room—the tendency to increase radiation flux and decrease burning time is a sound one. For larger fire compartments and more difficult targets—as, for example, in a factory—it is obvious that a slow input of heat over a long time is more effective.

Starting Fires in Japanese Houses

In the early days of the war against Japan, the view was strongly held that the destruction of Japanese cities by fire would be easy. This view was largely based on the recollection of the disastrous conflagration which followed the 1923 earthquake in Tokyo. Fire insurance experts, however, were not willing to concede that the normal incidence of fires was any higher in Japan than elsewhere, though the conflagration risk was greater, and this view was confirmed by the statistics of the Tokyo Fire Brigade which showed fewer fire calls per year than was received by the London Fire Brigade covering a similar area and population. A study of living conditions in Japan soon provided the reason for this low fire incidence. In Japanese houses, fire-places and furniture are almost non-existent and the only readily combustible objects are the light screens and shutters round the periphery of the room, and the hung ceiling.

In attempting to set fire to a Japanese house with an incendiary bomb, it is obvious that the attack must be concentrated against the screens and the hung ceiling. The advantage of the M.69 bomb for this purpose was immediately recognised ; the horizontal ejection of the gob of gel from the bomb ensures its intimate contact with the base of some part of the periphery, and the tall flames of the hydrocarbon gel, assisted by the surface flaming of any combustibles on which it happens to land, are an ideal medium for warming up and igniting the hung ceiling. In the dropping trials with this bomb at Dugway in the summer of 1943, extremely rapid fires were started in the Japanese houses there, and these usually started in the top floor showing that the penetration of the bomb was adequate, but not excessive.

The question which caused most concern was whether the speed at which fires reached the destructive stage at Dugway was typical of what would happen in Japan in the summer, when the wood moisture content was so much higher. As we have seen, the time to 'flash-over' is all important since it determines the possibility of successful counter attack by fire-guards. A large proportion of the fires at Dugway were completely destructive in less than two minutes, and in such a time the most efficient fire-guard has little chance. If fires take 10 minutes or more to reach 'flash-over' their susceptibility to fire-guard attack is high. All the Intelligence available during the war indicated that the Japanese were highly trained in home fire fighting and that they would be a serious menace. If this was so, then either a much greater density of bombs would have to be used than was at first envisaged, or else larger bombs would be required. It was obvious that more controlled tests were necessary before these points could be finally settled.

A testing programme was inaugurated in this country in the summer of 1944, and, in the autumn, an Incendiary Mission visited the United States to discuss with the C.W.S. and the N.D.R.C. the results obtained over there. As a result of discussion during this visit it was decided to erect some Japanese rooms at Edgewood, the design being such that all the parts could be prefabricated, and then conditioned to the required moisture content before assembly. The assembly took only 20 minutes so that there was little chance for the moisture content to change. At the same time the development of 'blaze' bombs was accelerated, since it was known that, even if the M69 was completely satisfactory, it was not being produced at a rate sufficient to satisfy both American and British needs in the event of an all-out incendiary attack on Japan. A new type of magnesium bomb was also developed with a parting charge between the body and the steel nose to push the magnesium towards the combustible material round the edge of the room. This modification was known as the 3 lb. magnesium bomb, since the weight was reduced to reduce the penetration.

The four Japanese test houses used in this country were designed by R.E.8 and erected at B.R.S. They were single-storeyed houses, and were generally referred to as Y1, Y2, Y3 and Y4. The test houses were built in line facing South with a 40 foot space between Y1 and Y2, and between Y2 and Y3, and a 3 foot space between Y3 and Y4. The close spacing of Y3 and Y4 was intended to resemble conditions in Japan, and it was hoped to carry out experiments on the spread of fire from one house to another.

The first twenty-nine tests, largely exploratory, were described in Panel Report No. 111. A further thirty-five tests were described in Panel Reports Nos. 113B, 115, 118, 119, 123, 135, and 139. The whole sixty-four tests were summarised and discussed in Panel Report No. 140, from which the following appraisals are taken.

3 lb. magnesium bomb

Fourteen tests were made with this bomb in various positions and the only occasions on which it showed promise of producing a fire of any magnitude were when the bomb was placed within range of a chest of drawers. Even so, the chest burned well only when it was made of thinner and more readily combustible wood (Western red cedar) than that originally used, which was Douglas fir.

4 lb. Mark IV magnesium bomb

This bomb was used in only one test, in which it set fire to two light screens, but not strongly enough to produce a rapidly spreading fire.

M69—6 lb. oil bomb

Twenty tests were made with this bomb; they were designed to give data from which an S.I.E. could eventually be calculated. In eight tests the gel landed where there was little chance of its causing a destructive fire. In the remaining tests there were six minor fires, two slow 'match' fires, two more rapid 'match' fires, and two which would, if allowed to continue, very probably have been classed as ' blaze ' fires. These last two occurred when the gel landed (*a*) in the eaves of the attic, and (*b*) between the shutters and glazed screen on the verandah.

In general, the results showed that a destructive fire, though not necessarily a rapid one, tended to develop whenever most of the gel landed at the base of the screens or shutters, but not when it landed at the base of doors or weather boarding. The calculated value of the S.I.E. of the M.69 in such a target was 0·42.

30 lb. ' J ' bomb

This bomb was used in five tests. Four of these were inside the building and they resulted either in ' blaze ' fires or in fires which would almost certainly have been classed as such if allowed to continue.

The remaining test was directed against the weatherboarding outside the building, and in this position the bomb did little damage.

The S.I.E. was calculated and found to be 0·95.

20 lb. ' J ' bomb

In fourteen tests, the 20 lb. ' J ' bomb produced three definite ' blaze ' fires and two ' probables '. In four other instances, ' match ' fires resulted.

When directed against an incombustible surface in a restricted space the bomb was still able to ignite the ceiling and cause a destructive fire, but this did not occur in a more open space.

When the bomb was placed as if it had penetrated through the tatami matting and floorboards it proved ineffective, but when only partially embedded in the floor so that the jet of flame passed vertically upwards it caused a rapid ' match ' fire.

In a separate test the explosive capsule of the bomb caused considerable damage to screens, mats, and glass, and caused the floor-boards and ceiling-boards to be dislodged ; this disturbance would have materially aided the incendiary effect of the bomb, quite apart from any deterrent effect of the explosion on the fire-guards.

In comparing the two ' J ' bombs the 30 lb. ' J ' appeared to possess some advantage by reason of its length of flame which enabled it to ignite the ceiling, screens and furniture simultaneously. The 20 lb. ' J ' bomb will ignite the ceiling if its flame impinges on the boards but otherwise it must depend on first igniting furniture or screens ; in some tests this lengthened the time before ' flash-over ' was reached.

The intense heat of the 20 lb. ' J ' flame sometimes appeared to defeat its own object by charring the wood too deeply so that it ceased to burn after the bomb was exhausted, but to compensate for this, the bomb flame was often seen to set fire, by radiation, to mats and other combustibles not directly in its path.

In one test all screens and shutters were removed, and the 20 lb. ' J ' bomb was aimed at the chest of drawers. No continuing fire resulted, partly because the bomb flame did not impinge fully on the chest. In a similar test with the 30 lb. ' J ' bomb a ' blaze ' fire resulted because the flames from the bomb and chest reached and ignited the ceiling boards.

The S.I.E. was found to be 0·80.

18 lb. Magnesium powder bomb

This bomb was still in the early stages of development at the time of the tests and it is not possible, therefore, to give any final verdict on its merits against Japanese domestic targets.

The tests showed that the dispersion of about 6 lb. of magnesium powder could cause very rapid ' blaze ' fires in buildings of this type, and even when all screens and shutters were removed a rapid ' match ' fire was produced. It was also shown, however, that the effect of the bomb depended to a large extent on the distribution of the powder, and it was for this reason that the tests with mortar-fired bombs at Tondu were organised. The first few tests gave promising results, but the work was suspended at the end of the Japanese War.

At Edgewood it was found that the fires started by M.69 bombs in the Japanese room there were slower than those at Dugway. Even in the most favourable positions no fires were obtained which reached the ' flash-over ' before 2 minutes, and only 10 per cent. became destructive in less than 5 minutes. However, 71 per cent. of fires had 'flash-over' times of 7½ minutes or less, and this was rightly considered to be a highly dangerous situation for fire-guards to cope with if the bombs were dropped in any reasonable density. This conclusion was more than justified by the results of the M.69 raids on Japanese cities in the spring of 1945.

A comparison of the test results at Dugway, Garston and Edgewood

In March 1945, a visit was paid by a member of the staff of B.R.S. to Dugway and Edgewood. By June 1945, fifty-five of the sixty-four Japanese house tests at Garston had been completed, and in Panel Report No. 128 a comparison was made of the results at all three places, and reasons were given for the differences in results obtained.

The Dugway results are recorded in T.D.M.R. No. 713, and D.P.G.S.R. No. 18. The Edgewood results are recorded in I.E.P. Report No. 8. Taking only the tests in positions which were common to the three structures, namely, in living quarters where the gel was located near screens or furniture and might be expected to produce more or less similar fires, the comparative figures are as follows :—

Table No. 5

Site.	Number of tests.	'A' fires.*	'B' fires.*	Total 'A' and 'B.'	Per cent. of 'A' fires.	Per cent. of 'B' fires.
Garston (static tests) ..	4	0	2	2	0	50
Edgewood (static tests)	9	6	3	9	67	33
Dugway (static tests) ..	14	10	4	14	71	29
Dugway (dropping tests)	18	16	2	18	89	11

* According to the Dugway classification : 'A' fires are those which pass beyond the control of the householder and require appliance attention within 6 minutes (A1 in 0–2 minutes ; A2 in 2–4 minutes ; A3 in 4–6 minutes). 'B' fires are those which eventually become destructive if left unattended. 'C' fires are those judged to be non-destructive.

Although there is room for some difference of opinion as to how large a fire must be before an appliance becomes essential, the classification has been adopted for convenience in this comparison.

The broad fact which emerges from this comparison is that whereas all the tests at Edgewood and Dugway in which the gel landed reasonably near screens or furniture gave either 'A' or 'B' fires, only 50 per cent. of those at Garston did so, and these gave only 'B' fires. Other small bombs, such as the 3 lb. or 4 lb. magnesium bombs also generally failed to produce destructive fires at Garston although bombs of equivalent size and action gave a number of 'A' fires at Dugway.

Four factors were recognised as having a possible bearing on these differences, namely :—

(i) Structural design and furnishing of the test buildings.

(ii) Moisture content of the timber.

(iii) Wood species.

(iv) Atmospheric conditions prevailing at the time of the test.

These will be discussed in turn.

Structure and furnishing

(*a*) In the upper living rooms at Dugway, where most of the fires started, the wall surfaces were almost 100 per cent. combustible, whereas at Edgewood and Garston an appreciable proportion of the periphery of the room consisted of plaster walls. This fact would give the bomb a higher S.I.E. in the room at Dugway, and would also tend to increase the rate of spread of fire there.

(*b*) In the same room at Dugway there was a low wall or step under the window screens ; this could (and apparently did) act as a barrier to gel ejected in that direction and enabled it to ignite the screens. In the absence of such a step at

Garston and Edgewood there were instances in which the gel passed harmlessly through the screens and fell outside (although these instances were eliminated in Table No. 5).

(*c*) The framework of the screens at Garston was appreciably heavier than that of the screens at Edgewood and Dugway and they were therefore less readily ignited.

(*d*) At Edgewood, the window screens, which were always backed by the shutters during the tests, were papered all over. Gel burning at the base of these screens soon burned off the paper and then attacked the exposed shutters. At Garston the corresponding screens were glazed, and the bottom row of panels was filled in with ¼ inch thick wood. Because of this the shutters were not exposed to the gel flame until the panels burned through.

(*e*) The boards of the Garston and Edgewood shutters were ¼ inch thick ; those at Dugway were ½ inch thick. This difference may have affected the results of tests involving principally the shutters, but would not have accounted for the greater speed of the fires at Dugway.

(*f*) The Dugway house included several solid wooden doors which were absent from the Garston and Edgewood targets. It is not known to what extent these doors were involved in the early stages of the fires at Dugway, but their effect might have been appreciable since they provided large areas of ' kindling ' to carry the flames to the hung ceiling.

(*g*) The difference in height between the hung ceilings at Garston and Dugway (8 feet 7 inches and 7 feet 11 inches respectively) had already been noted as a feature likely to favour the Dugway target, and the height in the Edgewood structure was made intermediate (8 feet 3 inches). From observations in several tests it was considered that even the difference of 4 inches between Garston and Edgewood could, in certain cases, materially affect the grading of a fire and might even make all the difference between success and failure.

(*h*) One particularly vulnerable position at Dugway, necessarily absent from the other two targets, was the space between the hung ceiling of the ground floor and the floorboards of the room above. In the dropping trials, three bombs landed in this position, two of which gave ' A ' fires. In the static-firing tests, six tests were made in this position, all giving fires which were graded as ' A.' Again, however, this factor was eliminated in the comparative table of results.

From all these observations it would seem probable that some at least of the disparities in test results could be explained on the ground of structural differences ; to assess the exact proportion of results so affected would require a more detailed study of the reports and, even then, would be difficult without a careful comparison of notes between those responsible for the various tests.

Wood moisture content

The effect of wood moisture on the results of incendiary performance tests has already been discussed at length ; there can be little doubt that the low moisture content at Dugway accounted in part for the very rapid fires produced there. There still remains, however, the wide disparity between the Garston and Edgewood results ; this cannot be explained on the ground of moisture content, for at both sites this is known to have been within the range 14–17 per cent. throughout the tests.

Wood species

The characteristics of a given species of timber which most affects its burning properties are its density and its oil or resin content. The woods chiefly used in Japan for domestic construction are the native sugi and hinoki, various native white pines and cedars, and to a lesser extent imported Douglas fir and hemlock. As a substitute for these native woods the U.S. Forest Products Laboratory recommended Port Orford cedar as the first choice, and Sitka spruce as the next best. At Garston, severe limitations on the supply of timber compelled the use of Douglas fir. At Edgewood most of the tests were done with Sitka spruce, but pine and fir were also included. At Dugway timbers of different species were used for different parts of the buildings and included fir, white pine, cedar, Russian pine and spruce.

In three series of experiments (*see* Panel Reports Nos. 106 and 116) in which panels of different species of wood, ½ inch thick, were ignited with equal weights of incendiary gel, there were significant differences between fir, spruce, pine, and cedar, both in their ease of ignition and in their subsequent burning. The fir was the least readily ignited although, once ignited, it maintained its own combustion for a longer period than the cedar which had ignited very readily. In the second and third series of tests the behaviour of spruce was found to be intermediate between that of fir and pine. In general, the denser the wood, the less readily did the panels burn.

Tests at Leeds University, F.P.R.L. and the U.S. Forest Products Laboratory have tended to confirm this as a broad generalisation and have shown in particular that Douglas fir, being generally denser than the other softwoods under consideration, is less easy to ignite and liberates its heat more slowly. Actually the density of this species varies rather widely and its burning properties may be expected to vary accordingly. The fir used at Garston unfortunately had a density of 0·57 as compared with 0·50 for the fir, and 0·40 for the spruce used at Edgewood, and with 0·37 for Japanese sugi.

Only two attempts were made in the Edgewood structure to compare the fir with the spruce and in these the other variables were not very strictly controlled; nevertheless they did afford some evidence that the fire developed less quickly when fir was used (*see* I.E.P. Report No. 8, Section VIII).

From all the evidence, therefore, it appears highly probable that the use of a rather high density Douglas fir at Garston was partly responsible for the relatively poor results obtained there with the M.69 and other small bombs. The differences in resin content of the various woods were hardly sufficient to have much bearing on the problem, excepting perhaps in the case of Loblolly pine, some of which was used at Dugway.

Atmospheric conditions

At Garston, the relative humidity of the air at the time of the tests in question ranged from 40 per cent. to 74 per cent. and averaged 67 per cent. At Edgewood, the range was from 40 per cent. to 88 per cent. with an average of 72 per cent. The conditions at these two sites were therefore very similar and there is nothing in these data to account for any appreciable difference in results.

Comparative data for Dugway are not available but it is well known (*see* Panel Report No. 90) that the mean relative humidity in that region is very much lower than 70 per cent., and that for the summer months it is more of the order of 40 per cent. This fact may possibly help to account for the rapidity of some of the fires at Dugway.

To sum up, the differences between Edgewood and Garston were found to be due partly to certain differences in structural detail, and partly to the use of a high density Douglas fir instead of the more appropriate Sitka spruce for the structural timber and furniture.

Similar factors would account for many of the differences between Dugway and Garston, especially as the Dugway structures presented more situations favourable to the rapid growth of fire than either of the other two targets. In addition, however, there is the probability that the moisture content of the wood at Dugway was well below the value of 15 per cent. which was finally agreed as reasonable, and the atmospheric humidity was well below 70 per cent.; this, it is thought, would be enough to account for the remaining differences.

Fire raising in industrial targets

It has already been pointed out that one important consequence of the R.A.F. practice of area bombing by night was that the type of building most commonly hit was the domestic dwelling. In testing incendiary bombs therefore the furnished room was the obvious test target to use.

The tactics of the U.S. 8th Air Force were different. Their policy was to attack specific industrial targets and interfere as directly as possible with the war production of the enemy. The necessary accuracy and bomb concentration could only be achieved by squadron bombing in daylight and accurate bomb sighting. This inevitably led to some sacrifice of aircraft bomb load owing to the necessity for providing greater protection against enemy fighters.

Now an incendiary bomb designed to set fire to the ' kindling ' in a furnished room is not necessarily the best weapon for starting fires in factories and other industrial complexes whose contents vary so much in ignitability. Much of the combustible material in factories is so heavy and fire resistant that it only burns in the late stages of a destructive fire ; it could never be ignited directly by any feasible type of incendiary bomb and is therefore unsuitable for use as a test target. At the other end of the scale it is common to find highly inflammable materials such as solvents, oil soaked rags, and wood shavings, but these are too readily ignited and irreproducible to serve as a basis for comparing incendiary bomb performances. In between these two extremes there are a large number of objects of widely varying ignitabilities, many of which could be easily reproduced and standardised and made the basis of a test target. These objects do not normally contain much ' kindling ' in the (*a*) form (thin wood panels) referred to previously which was used as a basis for the ' panel ' test. They more often contain a high proportion of bulk fuel which can only be ignited if there are good opportunities for mutual support. Thus, a 4 lb. magnesium bomb burning on the floor just outside a heavy wooden box will never start a self-propagating fire ; but if it is burning inside the box and can ignite all the inside surfaces, mutual support can be sufficient to enable the fire to take hold and become independent of the bomb.

The Incendiary Evaluation Project at Edgewood was set up primarily to study these various aspects of fire-raising in industrial targets, and to advise on the type of incendiary bomb from those in current production which would be most suitable for the purpose.

A preliminary survey of a number of factories in the United States showed that, although opportunities for mutual support varied greatly from one object to another, they were nevertheless frequent enough to justify incendiary attack. It was decided to select as test targets a number of articles which were common to a large variety of factories, and which varied in their ignitability over a range which very nearly included the bath of acetone at one end, and the 3 inch thick bench top at the other. The following is a list of the articles chosen, together with the approximate minimum amounts of incendiary gel which will ignite each in the most favourable location. The articles are fully described in IEP Report No. 9.

Cardboard cartons ..	1 oz.	Anywhere on, or at the side of, or between cartons.
Stack of wooden packing cases.	4 oz.	Anywhere in the narrow space between two or more packing cases.
Small-parts storage bin.	8 oz. to 1 lb.	Anywhere in one of the small compartments.
Work bench with tote box underneath.	$1\frac{1}{2}$ lb.	Inside the box or in the region enclosed by a side of the box and one table leg.
Heavy vertical wooden partition.	$2\frac{1}{2}$ lb.	Hard up against the partition and only if there are combustible objects on the other side so that mutual support can be provided when a hole is burned through and flames reach the far side.

Altogether, over 300 tests were carried out against these targets using the American M.50, M.69, and M.74 bombs. Since these bombs are so fundamentally different in their mode of action it was necessary to develop a separate testing technique for each. The methods adopted for testing them were as follows.

M.50

With this bomb most of the tests were carried out with static placement and firing of the bomb in and around the various targets. The effect of impact was reproduced by firing the bombs vertically downwards on to the targets from a mortar at the correct speed.

M.69

With this bomb a study was first made of the bouncing of the sock of gel from concrete and wooden surfaces. The action of the gel on the various targets was studied by placing the bomb on the ground and firing it so that the gel arrived at the target from all angles and distances. The action of the bomb when it penetrated the targets was studied with mortar-fired shots as with the M.50.

M.74

It is obvious that this is the most difficult bomb of all to appraise. Static burning tests were carried out with PT gel against all the targets as with the other bombs. A technique was also developed for firing yawed bombs giving different angles of gel arrival on to the target, and numerous tests were carried out in this way. In order to determine the average angle of gel arrival, airborne tests were carried out against the prototype industrial building on the dropping field at Edgewood. When hits were obtained it was possible to locate the hole in the roof made by the bomb on entry, the mark made by the bomb case on the floor, and the position in which the gel was burning; from these the angle of arrival of the gel could be calculated.

The results of the tests on all three bombs are given in I.E.P. Report No. 9. In order to use the experimental data thus obtained, a set of assumptions was drawn up which could be applied to the calculation of the S.I.E. for each bomb in a factory lay-out containing a reasonable distribution of all the five objects used as test targets. This was a very laborious and complicated procedure especially for the M.74 bomb where allowance had to be made for yaw, and the reader is referred to the report already quoted for full details. The final results of the analyses are collected together in Table No. 6. The fourth column under each bomb gives the recorded times in which self-sustaining fires were established. The fifth column states that all the targets except the bench and tote box are inherently capable of involving a roof once they are alight; this statement is justified because such objects are commonly high enough or present in sufficient quantity in a factory to produce flames that would reach the roof. This is of great importance since experience has shown that the chance of a complete burn-out in a factory is very much higher if the roof becomes involved.

Table No. 7 summarizes Table No. 6 in a somewhat more illuminating form. Time intervals of three, ten and forty minutes were selected to indicate the relative effectiveness of the bombs in starting quick fires, and the values in Table No. 6 which fell within these time intervals were added together for each target to give the chance of starting a fire. The values given in each column include the values for lesser times; thus, for the M.74, the chance that a bomb will produce a fire that will eventually involve the roof within forty minutes is 0·191. Of this total chance, 0·140 is the chance of such a fire being established within three minutes.

From Table No. 7, the following may be noted:

(*a*) For every one hundred functioning bombs entering a factory lay-out such as that used, fires will be started as follows:

Bomb.	Total fires.	Fires that can eventually reach the roof.		
		Total.	Self-sustaining within 10 min.	Self-sustaining within 3 min.
M.50	17	15	15	15
M.69	43	36	31	31
M.74	20	19	17	14

(*b*) For the number of bombs in a 500-lb. aimable cluster, again assuming penetration and 100 per cent. functioning, fires will be started as follows:

Bomb.	Total fires.	Fires that can eventually reach the roof.		
		Total.	Self-sustaining within 10 min.	Self-sustaining within 3 min.
M.50	19	17	17	17
M.69	18	14	12	12
M.74	8		6	5

Table No. 6

Analysis of fire-starting in a typical factory lay-out

Target.	M.50.					M.69.					M.74.				
	Chance of a hit.	Chance of a burn if hit.	S.I.E.	Time for fire to be self-supporting in min.	Will the fire reach the roof ?	Chance of a hit.	Chance of a burn if hit.	S.I.E.	Time for fire to be self-supporting in min.	Will the fire reach the roof ?	Chance of a hit.	Chance of a burn if hit.	S.I.E.	Time for fire to be self-supporting in min.	Will the fire reach the roof ?
Cardboard cartons															
Top	0·048	1	0·048	¼	Yes	0·054	1	0·054	¼	Yes	0·043	1	0·043	¼	Yes
Side	—	—	—	—	—	0·059	1	0·059	¼	Yes	0·022	1	0·022	¼	Yes
Floor around ..	0·017	1	0·017	1	Yes	—	—	—	—	—	0·005	1	0·005	1	Yes
Packing cases															
Top	0·045	1	0·045	½	Yes	0·045	1	0·045	½	Yes	0·042	0·93	0·039	1	Yes
Side	—	—	—	—	—	0·041	1	0·041	3	Yes	0·018	0·59	0·010	3	Yes
Floor around ..	—	—	—	—	—	—	—	—	—	—	0·002	1	0·002	5	Yes
Storage bins															
Top	0·039	1	0·039	1	Yes	0·045	1	0·045	1	Yes	0·024	0·75	0·018	40	Yes
Side	—	—	—	—	—	0·066	1	0·066	1	Yes	0·021	1	0·021	1	Yes
End	—	—	—	—	—	0·048	0·63	0·030	15	Yes	0·012	0·60	0·007	10	Yes
Floor around ..	0·001	1	0·001	15	Yes	—	—	—	—	—	0·006	1	0·006	5	Yes
Bench and tote box															
Inside tote box	0·023	1	0·023	1	No	—	—	—	—	—	—	—	—	—	—
Side of tote box	—	—	—	—	—	0·126	1	0·126	2	No	0·004	1	0·004	2	No
Floor around ..	—	—	—	—	—	—	—	—	—	—	0·007	1	0·007	3	No
Vertical wooden partition															
Side	—	—	—	—	—	0·028	0·63	0·018	15	Yes	0·027	0·60	0·016	10	Yes
Floor around ..	0·001	1	0·001	15	Yes	—	—	—	—	—	0·002	1	0·002	10	Yes
Total ..	0·174		0·174			0·512		0·484			0·235		0·202		

S.I.E. (static intrinsic efficiency) = chance of a hit × chance of a burn if hit.

Table No. 7
Analysis of fire-starting in typical factory lay-out
(Summarized from Table No. 6)

	M.50.			M.69.			M.74.		
	Self-sustaining fire within			Self-sustaining fire within			Self-sustaining fire within		
	3 min.	10 min.	40 min.	3 min.	10 min.	40 min.	3 min.	10 min.	40 min.
Fires which extended to the roof :									
Cardboard cartons	0·065	0·065	0·065	0·113	0·113	0·113	0·070	0·070	0·070
Packing cases	0·045	0·045	0·045	0·086	0·086	0·086	0·049	0·051	0·051
Storage bins	0·039	0·039	0·040	0·111	0·111	0·141	0·021	0·034	0·052
Vertical wooden partition	0	0·001	0·001	0	0	0·018	0	0·018	0·018
Sub-total (fires to roof)	0·149	0·150	0·151	0·310	0·310	0·358	0·140	0·173	0·191
Fires which do not extend to the roof :									
Tote boxes under benches	0·023	0·023	0·023	0·126	0·126	0·126	0·011	0·011	0·011
Total	0·172	0·173	0·174	0·436	0·436	0·484	0·151	0·184	0·202

It is seen that the individual M.69 bomb is twice as effective as the M.74 in starting fires in the factory lay-out which was used in the analysis, and that, on a 500 lb. cluster basis, the M.50 is the most effective of all. The difference between the M.69 and the M.74 is largely a result of the difference in the manner in which the bombs eject their gel rather than of any difference in incendiary content. Thus referring to Table No. 6 and considering only the hits on the sides, the ratio of M.69 to M.74 hits is as follows :—

Cardboard cartons	0·059/0·022 = 2·7
Stacks of packing cases	0·041/0·018 = 2·3
Front of storage bin	0·066/0·021 = 3·1
End of storage bin	0·048/0·012 = 4·0
Vertical wooden partition ..	0·028/0·027 = 1·0

For the particular floor loading assumed, it is apparent that lateral ejection from a bomb at rest is a more effective target-seeking mechanism than ejection, near roof level, from a bomb in yawing flight. A brief consideration of other floor loadings has not indicated that the conclusion would be changed thereby.

There are practical advantages in a bomb like the M.74 whose functioning is independent of the type of roof which it is required to penetrate. It is difficult to design a bomb which will function after it comes to rest and which at the same time can be used against a wide variety of targets. If the penetration of the M.69 had been increased, more difficulties would probably have been experienced with the ejection mechanism. When a specific target is being attacked, conditions can be adjusted accordingly, but for a stand-by weapon a bomb of the M.74 type is desirable. The great target-seeking power of a horizontally moving incendiary unit cannot, however, be overlooked and every effort should be made to adapt the principle to existing weapons.

Some additional tests were carried out at Edgewood using the British 20 lb. 'J' bomb against the industrial targets. These tests were repeated in this country at a later date, and the 30 lb. 'J' bomb was also tried. Both bombs were useless for anything except the cardboard cartons, as might be expected from the fact that they were designed to set fire to 'kindling' in which a continuing fire could be produced during the short burning time (2 minutes) of the bomb. In every case the targets were charred deeply and appeared to be burning vigorously while the bomb was active, but as soon as the bombs died out, the fires did likewise. With the 20 lb. 'J' bomb the force of the flame was such that it often tended to blow out flames which had become established on the outer parts of the target. To ignite bulk fuel it seems necessary, not only to have mutual support, but a rate of heat input slow enough to prevent excessive surface charring of the wood before self-propagation of flame has been established.

This section cannot be closed without a further brief reference to the airborne tests which were carried out at Edgewood in the summer of 1945. The prototype industrial building used for these tests is in three sections. Section A has a saw-toothed roof of alternate wood and metal roofing. Section B has a flat reinforced concrete roof. Section C has three stories built in reinforced concrete. Sections A and B were filled with the standard targets used in the previous tests to a floor loading density of about 5 per cent., and when a cluster of bombs burst over the structure and penetrated the roof their action against the wooden targets could be studied under actual conditions of use in operations. One disadvantage of this method is that it is slow and wasteful of bombs, and every time holes are made in the roof they must be repaired to keep the rain from wetting the targets. However, taken in conjunction with static firing tests, these dropping tests were invaluable, as they indicated the sort of conditions which arise which might otherwise have been overlooked.

For some bombs this method is about the only one which can be used. For example, the American M.74 bomb—a 100 lb. gel bomb similar in mode of action to the British 30 lb. gel bomb—is too large to be fired from a mortar, and no form of static firing could ever reproduce the distribution of gel which is obtained in airborne drops. A considerable amount of testing work was actually done with this bomb at Edgewood in an effort to find the most effective form of burster and gel, and it is hoped that a report of this work will eventually become available in this country. It is difficult to see how any satisfactory post-war testing programme could be carried through in this country without similar facilities.

Laboratory experiments on the ignition of wood by radiation, and its subsequent burning

In addition to the actual tests on incendiary bombs, a number of laboratory studies were made of the factors which control the ignition and subsequent burning of wood. It was not possible to apply these results as they were incomplete at the time, but subsequent experience has shown that, had we been in the possession of information now available from these experiments, much time and money would have been saved. It is imperative that this work should continue until all the factors controlling the ignition of burning of wood are thoroughly understood; only then will it be possible to design the ideal incendiary bomb for any purpose.

Measurements of 'Wood flammability under various conditions of irradiation' are described in the U.S. Report OSRD No. 432 (March 1942).

The wood used was mostly in pieces 1 inch by 6 inches by 12 inches. About 8 inches square of each sample was subjected to irradiation from an electric radiator parallel to the wood surface and a few inches away, and a water-cooled screen with a 3 inch square aperture limited the beam of radiation falling on the wood. The wood was in most cases placed in the vertical position, but in a few cases it was horizontal and irradiated from below. Very little difference was found between the two cases. In a few tests the edge of the wood was irradiated, and in others, the flat wood surface normal to the beam of radiation projected half way into the beam.

Several species of wood were used, mostly planed spruce, but also rough spruce, planed oak, planed Western pine, and New England white pine, both rough and planed. The samples were conditioned for at least 5 days in air at either 75 per cent., 32 per cent. or zero relative humidity. The actual moisture contents were apparently not determined.

The radiation intensity could be varied from 10,000 to 50,000 B.Th.U. per square foot per hour; the corresponding radiation temperatures are

10,000 B.Th.U./ft.^{2}/hr.	600° C.
20,000 B.Th.U./ft.^{2}/hr.	760° C.
30,000 B.Th.U./ft.^{2}/hr.	870° C.
40,000 B.Th.U./ft.^{2}/hr.	960° C.
50,000 B.Th.U./ft.^{2}/hr.	1,030° C.

These radiation temperatures much exceed the temperature actually attained by the wood surface up to the time of self-ignition; the temperatures as measured by a fine wire thermocouple pressed flush with the wood surface in a knife slit, and the total radiation received up to the time of ignition, were as follows :—

15,000 B.Th.U./ft.^{2}/hr.	Total radiation 268 B.Th.U./ft.^{2}	480° C.
19,400 B.Th.U./ft.^{2}/hr.	Total radiation 113 B.Th.U./ft.^{2}	490° C.
40,000 B.Th.U./ft.^{2}/hr.	Total radiation 44 B.Th.U./ft.^{2}	268° C.

These temperatures clearly depended on the total radiation received up to ignition.

For self-ignition, the minimum radiation intensity was 20,000, causing ignition in 25 seconds; 25,000 had this effect in 13 seconds, and 3 seconds sufficed for intensities of 50,000 or more. The corresponding total radiations up to the time of ignition were 140, 90 and 40 B.Th.U./ft.^{2}, showing that less heat is required when the radiation is more intense.

Measurements were also made of the intensities of irradiation that will produce self-burning after the gases from the wood have been ignited by a small 'pilot' jet ½ inch from the wood. The minimum rate was 9,000 B.Th.U./ft.^{2}/hr. causing ignition in 60 seconds; at 25,000 intensity the time was reduced to about 5 seconds the total heat required being, as before, less for the more intense radiation.

This is an interesting fact in relation to the speed of 'flash-over' in a furnished room. It was pointed out earlier that if the wood in the primary fire was dried out it would burn faster, radiate more intensely, and consequently raise the room to the 'flash-over' in a shorter time. It is seen now that there is a double advantage, in that at the higher intensity the transfer of heat is more efficient, and less total heat is required to raise the rest of the room to the ignition point. It helps to explain also the rapid action of a bomb like the 30 lb. 'J' and the still more rapid action of the magnesium powder bomb.

Little difference was found between the flammability of the different species tested, except that oak needed slightly more time for ignition than sufficed for the other varieties. Moisture content also had little effect.

The flames produced on ignition were found not to persist. This is a condition with which we are now well acquainted since the samples were 1 inch thick and well above the critical thickness for self-propagation of flame in an isolated panel. To maintain the flame for 10 minutes or more by sustained irradiation, an intensity of about 10,000 B.Th.U./ft.^{2}/hr. was needed. With low intensity sustained radiation (5,400 B.Th.U./ft.^{2}/hr.) after ignition, the persistence of flame was four times as great for the driest wood as for the moistest. This difference disappeared when the sustained intensity was raised to 10,000. Persistence was longer for cracks or edges than for flat surfaces. In the absence of sustained irradiation after ignition the persistence of flame was longer on fires started with low intensity radiation, and therefore, with a greater total radiation up to the time of ignition.

The above experiments confirm what has been noted so often in incendiary bomb tests, namely, that the most favourable conditions for the ignition and continued burning of an isolated wood object are a moderate initial heat supply, and a low sustained supply of heat after ignition. A fiercer heat distils inflammable gases from the wood at a too rapid rate, and only chars the outer layer; this charred layer may glow under a sufficiently intense supply of heat, but it does not burn readily; it also retards the flow of heat to the lower layers, and so reduces the further distillation of the wood. The ignition of a number of combustible surfaces in a confined space is rather different. The more intense the radiation the better, since the irradiated surfacesare brought to the ignition point more quickly and with a smaller total quantity of heat. Once they are ignited, mutual support is sufficient to maintain surface flaming long enough for the fire to establish itself independently of the initial source of heat.

The principle of a moderate initial heat supply, and a low sustained supply of heat after ignition was, of course, utilised in America in the development of incendiary bombs based on burning gasoline gels. While gasoline has the highest heat of combustion of any known incendiary, it can be made to burn at almost any rate by suitable thickening.

Experimental work on the ignition of wood by radiation was carried on more exhaustively at a later date at the Fuel Department at Leeds University. In these experiments the heater consisted of eight 'Glober' elements dissipating 9 kilowatts, backed with fire brick to afford a uniform source of radiation. The radiating area was defined as a central 3 inches diameter hole in a water-cooled screen immediately in front of the heater. The sample was placed behind a second water-cooled screen, both being mounted on a carriage running along fixed guides so that the radiation intensity could be varied. The radiator was calibrated against a water flow calorimeter. The species of wood tested were oak, pine, birch and gurjun; the samples were 6 inches square and of different thickness ($\frac{1}{8}$ inch to 1 inch) and moisture content.

As with the American experiments, measurements were made of the times to pilot-ignition and self-ignition. The values obtained were not in good agreement with the American values, but the general conclusions were similar. They may be summarised as follows :—

(a) Self-ignition was affected at some 13,000 B.Th.U./ft.^{2}/hr. independently of the thickness of the sample. Pilot-ignition was obtained at 5,000.

(b) The times taken varied to some extent with species, but chiefly with moisture content and intensity of radiation. Thus pilot-ignition with 10 per cent. moisture content wood took approximately 200 sec. at the minimum radiation intensity of 5,000, but only 15–20 sec. at 13,000.

(When testing magnesium bombs on the 'panel' test at Leeds it was usually found that birch plywood panels ignited after 25 sec. at the extreme range of 14 inches, so that the radiation intensity there must have been of the order of 10,000 B.Th.U./ft.^{2}/hr.)

(c) The lower the radiation intensity before ignition the greater the chance of continued burning after ignition, and the greater also the total amount of heat required up to the ignition point.

(In these experiments irradiation was maintained after ignition and it was possible eventually to produce a continuing fire in 1 inch thick wood with a radiation intensity of 10,000 B.Th.U./ft.^{2}/hr. It is not known whether the burning of these samples would have continued if the radiation had been cut off after say 3 min., 6 min., 9 min., or 12 min., *i.e.*, at times comparable with the active lives of most incendiary bombs.)

(*d*) The heat input for continued burning after ignition varied somewhat with species, and with moisture content and thickness. The type of char produced also had an effect.

(*e*) The temperature of the wood at the back of the sample remained constant at or near 100° C. until all the moisture was evaporated.

(*f*) The continued burning of plywoods was largely dependent on the nature of the bonding material.

A number of hypotheses concerning the ignition and burning of wood were put forward in Panel Report No. 144 in an attempt to explain the phenomenon of successive 'flash-over' which had been noted on a number of occasions at I.B. Cottage and elsewhere. After the first main 'flash-over' the fire would burn vigorously for some time and then clear, and die down in intensity, but this would be followed by a second 'flash-over,' and occasionally a third and fourth. This was noticed more often when the moisture content of the wood was fairly high. These hypotheses appear to be reasonable, but so far there has been no opportunity to verify them experimentally.

The effect of bomb density and distribution of the effectiveness of incendiary raids

The original terms of reference of the I.B.T.P. restricted it to a study of the intrinsic properties of incendiary bombs. This study resulted, as we have seen, in the establishment of the 'panel' test, and the application of the results so obtained to the calculation of a static intrinsic efficiency or S.I.E. for the bomb and target being considered. In practice, for a variety of reasons, a proportion of the bombs which hit buildings do not arrive at the level of which the test target is typical, and of those that do, a proportion fail to function correctly. Thus in operations, the chance that a bomb falling on to a building will fall into such a position that it will start a continuing fire is less than that given by the S.I.E. This chance is known as the dynamic intrinsic efficiency or D.I.E. of the bomb, and is of course the product of the S.I.E., and a number equal to the proportion of bombs which, having hit the building, penetrate to the desired level and function correctly.

The D.I.E. still fails to take into account the effectiveness of fire-guard measures, and, in the last resort, the only property of the bomb of real interest is its overall efficiency, which may be defined as the proportion of the bombs dropped on to buildings which start destructive fires despite the activities of the fire-guards. This aspect of incendiary bombing was first discussed in Panel Report No. 6 (July 1942). This was followed in December 1942 by Panel Report No. 12a in which, as we have already seen, an attempt was made to estimate the probable change in the number of destructive fires which would be produced per aircraft load of bombs by a reduction in the amount of magnesium per bomb and a corresponding increase in the number of bombs (*see also* Panel Report No. 143).

Both investigations required a knowledge of ground bomb density from an individual container and from a stick of containers, and the mathematical methods developed for analysing stick patterns were described in Panel Reports Nos. 15 and 29.

It was realised at this time that fire-guard activity would be profoundly affected by bomb density, and in March 1943, an investigation was made into the optimum density of incendiary bombs which was described in Panel Report No. 21. It was suggested that the incendiary weapon was the stick of bombs rather than the individual bomb, and that although it was still important to improve the intrinsic properties of the bomb itself, the way in which the bombs were dropped was of equal, if not of greater importance.

The study of this aspect of the problem was further stimulated by the issue in September 1943 of a paper by R.E.8 entitled 'The relation between the density of incendiary attack and the extent of visible damage to buildings in the central zone of German cities ' which was later reproduced as Panel Report No. 43. This paper raised a number of very controversial issues which were eventually crystallised into a difference of opinion between those, on the one hand, who believed it was best to distribute the bombs uniformly over the target area even at some sacrifice of density, and those, on the other hand, who as firmly believed that the bombs should be dropped in very dense parallel sticks so that fire-guards in the stick areas would be overwhelmed, and the maximum possible advantage taken of the sideways spread of fire by radiation across the areas uncovered by sticks. A comparative assessment of the two methods involved a knowledge of the effectiveness of the enemy's fire-guard resources and of the mechanism of fire-spread which were not available at the time. Towards the end of 1944 a theoretical study was made of the principles of spread of fire in built-up areas (*see* Panel Report No. 99), and some time later, radiation measurements were made when one of the Japanese houses at B.R.S. was allowed to burn to destruction. A proposal was also considered for the erection of twenty Japanese houses for fire-spread experiments, but this was never approved and the information has never been obtained.

In December 1943 D.Arm.D. invited the Panel to compare the operational results to be expected from a raid with 500 lb. clusters each containing 106—4 lb. magnesium bombs, and one with 500 lb. clusters each containing 14—30 lb. 'J' bombs. In Panel Report No. 60, an estimate was given of the D.I.E. of the 30 lb. 'J' bomb based on all the experimental evidence available, for comparison with the value of the D.I.E. of the 4 lb. bomb, but in replying to D.Arm.D. it was again pointed out that a fair comparison of the operational results on a weight basis could not be made without a consideration of the effectiveness of the methods adopted by the enemy for preventing small primary fires from growing to the destructive stage, and this information was not available to the Panel.

These operational problems had become so acute by the beginning of 1944, that the Air Ministry finally decided to set up a new Incendiary Panel under the chairmanship of the Chief Scientific Adviser, with a membership especially qualified and informed to be able to adjudicate on the various differences of opinion which had developed, and from this time onwards the I.B.T.P. ceased to have any direct interest in these problems. However, when the Panel was transferred from M.H.S. to M.A.P. in November 1944, the terms of reference were enlarged so as to include the study of the stick of bombs and not only the individual bomb, since it was now generally agreed that this was the real attack unit which must finally be considered.

Some thoughts on the future development and testing of incendiary bombs

Research

The poor aimability of the small magnesium bomb was a cause of continual concern. The Germans developed containers of a sort, but these were only intended to secure the greater concentration which results from a lower separation of the individual bombs, and they were not designed ballistically to be aimable. Our own early practice was to release the bombs from a container which stayed in the aircraft so that the bombs were even less aimable. It was a necessary consequence of this method of delivery that specified targets could not be hit with any degree of certainty, and the method usually adopted, therefore, was to drop large numbers of these incendiaries over extensive inhabited areas so that the bombs had a reasonable chance of hitting something. This meant, as we have already seen, that the domestic dwelling was more frequently hit than any other type of building for the simple reason that there are so many more of them. The wisdom of such a procedure was often questioned, but an interesting comment on the probable effects of such bombing is to be found in the following quotation from the Summary Report of the U.S. Strategic Bombing Survey.

' The city area raids have left their mark on the German people as well as on their cities. Far more than any other military action that preceded the occupation of Germany itself, these attacks left the German people with a solid lesson in the disadvantages of war. It was a terrible lesson ; conceivably that lesson, both in Germany and abroad, could be the most lasting single effect of the air war.'

This comment is the more striking since the U.S. Air Forces in Europe were generally averse to area bombing, although they used it later with telling effect against the cities of Japan.

However, as the European War progressed, the so called ' aimable ' cluster was developed which made it possible to attack specific targets with less uncertainty, although the practice of night bombing by the R.A.F. still made the success of this development dependent on accurate target identification and marking. Even the daylight bombing by the U.S. 8th Air Force was restricted in its accuracy by all sorts of unforeseen operational difficulties. Towards the end of the war, however, more and more success in hitting the target was attained by both Air Forces, and ' precision jettisoning ' became a thing of the past. It is evident that as time progresses, target identification and marking will still further improve, and there will be rapid advances in the design of amiable clusters and bomb sighting equipment, and, of course, of guided missiles.

Inevitably such a development means an alteration in outlook as to the type of target to be attacked. The object of any aerial bomb attack is to reduce the ability of the enemy to wage war, and this can be done most effectively by destroying the factories and workshops in which instruments of war are being produced. It is for this reason that so much space was given in this monograph to the methods developed at Edgewood for the study of fire-raising in industrial targets. This is only a beginning and very much more needs to be done.

First and foremost, and quite independently of what incendiary bomb is used, a much more extensive study must be made of the mechanism of the ignition and continued burning of wood, such as has already been attempted. War-time development of incendiaries was considerably retarded by our lack of fundamental knowledge on this subject, although it was not always realised at the time.

Further species of wood could be studied with advantage, but more particularly an attempt should be made to separate the effects of density, diffusivity, and conductivity. Experiments should also be made with larger samples more representative of the average target than the small samples used both by the O.S.R.D. in America, and at Leeds, and with groups of samples arranged to represent the sort of configuration that exists in practice between the different surfaces of the average target. The effect of confinement of heat should also be studied.

At the same time a much more exhaustive mathematical study should be made of the problem, in collaboration with the individuals who are actually doing the practical work, so that new avenues of experimental woık can be opened up.

Development

When it comes to the more practical problem of the development of an incendiary bomb for the future—especially in view of the tendency already noted for the emphasis to be on industrial targets—the following requirements must be borne in mind, as their importance has already been firmly established:—

(*a*) Simplicity in design and manufacture.

(*b*) Smallness of the individual unit consistent with incendiary efficiency.

(*c*) Ability to set fire successfully to a wide range of combustible objects.

(*d*) Ability to function successfully in a wide variety of types of buildings.

(*e*) Ability to propel its incendiary constituents more horizontally than vertically, once inside the target.

(*a*) Requires no comment since, in the event of war, production must be expanded rapidly, and this can only be done if all the complications of manufacture have been reduced to a minimum.

(*b*) Follows from elementary numerical considerations of the total capacity of an aircraft in relation to the number of points of fire which can be established by its load of incendiaries. The main objection to the use of a small bomb—that it was subject to fire-guard control—was removed in the high saturation attacks which were used at the end of the war, and which would undoubtedly be used again, even at the expense of individual bomb efficiency.

(*c*) Requires the use of an incendiary agent which liberates its heat slowly and at a fairly low intensity. Such a fuel is capable of igniting, not only ' tinder ' and ' kindling ', but also ' bulk-fuel ' ; whereas a high intensity radiation bomb like the magnesium powder bomb is only capable of firing 'kindling' and 'bulk-fuel' if there are unusually favourable conditions for mutual support, coupled with a fairly close confinement of the heat.

(*d*) Requires some form of functioning of the bomb in flight after it has been activated by penetration at the roof. In connection with the American M.74 bomb it was noted that the design of an incendiary bomb which would come to rest at the most suitable place in every type of target was almost impossible. This requirement is to some extent in conflict with (*e*) since perfect horizontal projection is most easily obtained from a bomb at rest in the target. It is possible, however, that the incendiary bomb of the future will be a cross between the British 30 lb. gel or the American M.74 bombs and the American M.69. This may possibly be achieved by introducing a suitably short delay before bursting, and slowing the bomb down so that, after penetration, any sideways component of gel velocity after ejection produced by yawing or turning of the bomb will be appreciable compared with the residual downward velocity due to the motion of the bomb. In this way it may be possible to increase the apical angle of the cone within which the gel is ejected, and thus increase the target-seeking propensities of the contents.

The minimum requirements for any Post War Incendiary Evaluation Project in this country may be easily laid down from the results of our experience in this war. The burning of wood is dependent very largely on moisture content, species, air supply and atmospheric condition, and in consequence these must all be closely controlled for the results of any tests to have any value. It is only possible to eliminate draughts and other unusual air flow conditions by carrying out the burning tests in a large fireproof building similar to the one at Edgewood Arsenal. The building should be equipped with adequate arrangements for the extinction of fires and drainage of water, and a sufficient number of powerful fans for clearing the smoke after each test. It should be provided with a steel framework above, capable of supporting a number of different sized mortars or other devices which can be used for firing bombs into the building at any required angle. Side by side with this must be smaller buildings for the storage and conditioning of the timber for the tests.

For the larger bombs which cannot be fired from mortars there must be provision for airborne tests against a building fitted up with the necessary combustible targets, similar to the prototype industrial building on the field at Edgewood Arsenal. There must be provision for continuous and rapid repair work to the roof.

In addition to the long term development work indicated there are a number of special tests on existing weapons which would provide useful data for development work.

(*a*) A complete study of the range of action of the magnesium bomb using the Leeds 'panel' test, with all the possible permutations and combinations of alloy, size, shape, filling, etc. This is specially important in view of the pronounced superiority of the small magnesium bomb on the industrial targets at Edgewood, and because of the large difference that was produced by the small change in design from the Mark III to the Mark IV bomb.

(*b*) A study of the apical angle of the cone of ejection of the gel from a 30 lb. bomb in relation to its velocity after penetration.

(*c*) Further studies of gels in an effort to obtain one which will hold together more effectively when ejected from the bomb. In the U.S. tests, indications were that the G.R.S. (synthetic rubber) gel had a distinct advantage in this respect over Napalm gasoline and P.T. in the American M.47 bomb, and there is obviously much more work to be done.

Finally, referring back to the original statement of the problem, it is obvious that very little is still known about the spread of fire in buildings and from one building to another. Direct work of this sort is costly and unpopular in a time of such acute housing accommodation as the present, but much information could undoubtedly be obtained from the Departments responsible for the study of civil fires with whom, it is recommended, a close liaison should be maintained.

APPENDIX 4

BRIEF NOTES ON THE VARIOUS MARKS OF 500 LB. M.C. BOMB

Mark

I. Welded steel plate : charge/weight ratio 50 to 51 per cent.

II. Forged : of great comparative strength with a similar charge/weight ratio. The most satisfactory of all 500 lb. M.C. bombs.

III. A cast steel bomb : charge/weight ratio 42 per cent.

IV. A similar bomb but of smaller dimensions, made by Messrs. Stanton on plant used for G.P. bombs. Charge/weight ratio 40 to 41 per cent.

V. Cast bombs in which the position of the centre of gravity was outside the limits imposed by the specification. Only a small number were made.

VI to IX. As I, II, III and IV, but with American lugs and some very minor modifications.

X. A forged bomb with a solid nose made by Messrs. Jarrow Metal Industries on S.A.P. plant.

XI. A strengthened Mark VII bomb, fuzed tail only, and with solid nose : the tail structure was specially strengthened to withstand tail side impacts.

XII. As Mark XI but with provision for nose fuzing. (*Note :* Neither XI nor XII went into production.)

XIII. Scarff welded bombs of Messrs. Stewart and Lloyd manufacture : hitherto scrapped but pressed into limited service (nose instantaneous fuzing only) to meet the increasing demand in 1944.

XIV. Similar to Mark X with a 2-inch diameter fuze.

XV. A specially designed bomb for under-water use. It is similar to Mark XII but has provision in the tail for dual fuzing—hydrostatic or time. Still in early development stage (October 1945).

APPENDIX 5

8,000 LB. H.C. BOMB.—DETONATION TRIALS

Summary of results

Serial No.	Bomb.	Filling, including weight.	Explodering system.	Wall thickness.	Initiation.	Results.
		lb.		inch.		
1	8,000 lb.	Amatol 60/40 5150	All through, pressed T.N.T.	½	Nose	The values of + impulse from each of these two bombs were only about the same as those previously obtained from a 4,000 lb. H.C. bomb.
2	8,000 lb.	Amatol 60/40 5150	All through, pressed T.N.T.	½	Side	
3	Nose section of 8,000 lb. H.C. bomb	Amatol 60/40 2660	All through, pressed T.N.T.	½	Nose	+ impulses less than half those obtained from a 4,000 lb. H.C. bomb. (The diameter of serial No. 3 is 38 inches and that of a standard 4,000 lb. H.C. is 30 inches.)
4	8,000 lb.	Amatol 60/40 5100	32 lb. P.E., central ..	½	Central	+ impulses not greatly different from serial Nos. 1 and 2.
5	8,000 lb.	Amatol 60/40 5200	All through, pressed T.N.T.	¼	Nose	+ impulses approx. 30 per cent. less than bombs in serial Nos. 1 and 2.
6	8,000 lb.	Amatol 60/40 5200	All through, pressed T.N.T.	¾	Nose	+ impulses better than serial Nos. 1, 2, 4 and 5, but 30 per cent. less based on results of 4,000 lb. H.C. bombs.
7	8,000 lb.	R.D.X./T.N.T. 60/40 5333	All through, pressed T.N.T.	½	Nose	+ impulses in good agreement with 4,000 lb. H.C. bomb. Assumed that filling in previous serial numbers had not given complete detonation.
8	8,000 lb.	Amatol 60/40 5129	C.E. pellets and two R.D.X./T.N.T. 60/40 booster rings in each section.	½	Nose	+ impulses 30 per cent. less than those based on results of 4,000 lb. H.C. bomb.
9	8,000 lb.	Amatol 60/40 5100	No central tube. Three all through C.E. exploders with layer of R.D.X./T.N.T. 60/40 at nose end of each section.	½	Nose	Rate of decrease of + impulse with distance much less, compared with previous bombs. Difficult to draw definite conclusions from this serial number.
10	8,000 lb.	Amatol 60/40 5100	2-inch 'fluted' exploder C.E./T.N.T. 70/30.	½	Nose	Slightly better performance than serial Nos. 1 and 2, chiefly at greater distances.
11	8,000 lb.	R.D.X./Amm. Nit./T.N.T. 9 : 51 : 40.	All through, C.E.	½	Nose	+ impulse approx. 7 per cent. below serial No. 7.

APPENDIX 6

DETONATION TRIALS OF INCREASED CHARGE/WEIGHT RATIO BOMBS

This is a copy of an interim report (No. 117/44) by the Armament Research Department. The details given in the account of the increased C/W ratio 4,000 lb. H.C. bomb were derived from a later report.

Bombs, H.C., 4,000 lb. of increased charge/weight ratio

Summary of data on increased blast effect from bombs having thin steel or aluminium alloy cases

SUMMARY

(*a*) In confirmation of estimates previously submitted, trials in Bombs M.C. 500 lb. Mark III and Bombs H.C. 4,000 lb. have shown that a substantial improvement of blast performance can be obtained by an increase of charge/weight ratio, *e.g.*, by the use of thin steel or aluminium alloy cases.

(*b*) A design of Bomb H.C. 4,000 lb. with ⅛ inch steel case has been prepared and for a particular filling this bomb gives a mean damage area about 25 per cent. greater than that given by a Service bomb with $\frac{5}{16}$ inch steel case, together with a saving in total weight of about 350 lb.

This design is considered by C.E.A.D. to be suitable for immediate production.

(*c*) Trials have been carried out with a Bomb H.C. 4,000 lb. with a $\frac{5}{16}$ inch aluminium alloy case. For a particular filling this bomb gives a mean damage area about 40–45 per cent. greater than that given by a Service bomb ($\frac{5}{16}$ inch steel case), together with a saving in total weight of about 600 lb.

The mean damage area for an aluminium alloy bomb filled Minol 2 is nearly three times that for a Service bomb ($\frac{5}{16}$ inch steel case) with the original filling of Amatol 60/40.

Further consideration of the manufacturing difficulties experienced with the aluminium cased bomb, and strength tests by R.A.E. will be necessary before a satisfactory design can be prepared.

References : X.A. 530/2. O.B. Procs. 25987
27433
27714

Trials in bombs, M.C., 500 lb., Mark III, with cast aluminium cases—O.B. Proc. 25987—A.R.P. Explosives Report 88/44

These trials were carried out to determine the effect of a case of cast aluminium alloy on the blast performance of a bomb. The proposal to carry out this trial arose from a discussion concerning the high values of positive blast impulse intensity recorded for the German Mine Type C which had an aluminium alloy case. Although the average level of blast impulse intensity for the C Mine was approximately in agreement at the nearer distances with the estimated values, the rate of decay of impulse intensity with distance was abnormally low, and it was considered desirable to determine whether the possible 'afterburning' of the aluminium alloy case made any appreciable contribution to the observed blast impulse intensities.

For convenience of testing procedure, trials were arranged in the first instance with bombs having cast aluminium bodies generally similar to the service Bomb M.C. 500 lb. Mark III although it was recognised that operational use of aluminium alloy bombs of the M.C. type was unlikely.

The internal volume of the bombs actually supplied was about 2·33 cubic feet as compared with 2·13 cubic feet for the service Bomb M.C. 500 lb. Mark III. The aluminium alloy, had the following approximate composition :—

	Per cent.	
Copper	3	
Silicon	3 to 4	Maximum stress
Iron	0·6	9·5 tons/sq. in.
Nickel	0·1 to 0·2	
Magnesium	0·1	Elongation
Manganese	0·5	2–2·25 per cent.
Zinc	0·1	
Aluminium	Remainder	

Measurements of blast impulse intensity were made by A.R.D. and R.R.L. using four lines of piezo electric gauges over the range 30 feet to 150 feet.

The average values of intensity of positive blast impulse taken over the range of measurements are given below taking the value for R.D.X./T.N.T. (Steel case) = 100.

	A.R.D.	*R.R.L.*
Amatol 60/40 (Steel case)	82·7	82·0
Amatol 60/40 (A.1 case)	111	112
R.D.X./T.N.T. 60/40 (Steel case)	100	100
Minol 2 (A.1 case)	150	152
Minol 2 (Steel case)	118	118

The thickness of the steel and A.1 cases was about the same (0·4 inch to 0·5 inch).

The increased values of blast impulse intensity for the bombs with aluminium alloy cases agree closely with those estimated from a consideration of the increased charge/weight ratio so that any contribution to the blast impulse intensity arising from afterburning of the aluminium alloy case must be small.

It will be noted that a substantial increase of blast impulse intensity arises from the substitution of an aluminium alloy case for steel. For Amatol 60/40 the increase is about 35 per cent. and for Minol 2 the increase is in the neighbourhood of 30 per cent.

Bombs, H.C., 4,000 lb.—Trials of bombs with thin steel and aluminium alloy cases—O.B. Procs. 27433 and 27714

Estimates of the increased blast performance of H.C. bombs of very high charge/weight ratio, and tentative designs of bombs with thin steel and aluminium alloy cases were submitted by D.R.R.L. (A.C. 5866–S.D. 371).

The position was reviewed at a sectional meeting of the Static Detonation Committee on 30 March 1944 and suitable trials in Bombs H.C. 4,000 lb. were recommended.

Static detonation trials of Bombs H.C. 4,000 lb. filled Minol 2 (three rounds) and R.D.X./T.N.T. 60/40 (three rounds) having aluminium alloy (D.T.D. 213) and ⅛ inch steel cases were carried out at Shoeburyness with service bombs (5/16 inch steel cases) filled R.D.X./T.N.T. (four rounds) as controls.

The following information on the design of the bombs had been communicated by C.E.A.D.

Steel case bomb

The outline is similar to that of the present bomb and has a case of ⅛ inch mild steel plate with a longitudinal welded seam. It is reinforced by an internal beam and circumferential T ring. Internal pads are fitted at the suspension and lifting lug positions. The empty case complete with the fittings weighs 450 lb. compared with 887 lb. for the standard Mark IV Bomb. This bomb has been subjected to strength tests at R.A.E. and satisfies the requirements of specification D.T.D. 1051 for Class III stores. Explodering is similar to that employed in the Mark IV Bombs.

Aluminium case bomb

The bomb case produced in Aluminium alloy to D.T.D. 213 has been designed with the same outline and same wall thickness as the standard bomb, reinforced internally with a T ring at the suspension lug position, and a stiffening ring under each of the hoisting bracket positions. In order to facilitate manufacture on the experimental production the bodies were swaged and the stiffening rings omitted, these swagings accommodating external hoisting bands to which lugs could be fitted. The empty case with stiffening ring weighs about 350 lb. The explodering is similar to that employed in the Mark IV Bomb.

In view of the amount of welding involved even allowing for the adoption of swagings, it proves to be a much more difficult bomb to produce than the mild steel case. If the required production effort can be made available it is considered that the original design employing stiffening rings should be adopted in preference to the swaged body with the necessary inconvenience to the service of external suspension bands. Strength tests at R.A.E. are required to confirm the efficiency of either type of construction.

Both the steel and aluminium cases are liable to damage in transit if not carefully handled and some special protective fittings will be required.

Blast pressure measurements were taken by A.R.D. and R.R.L. using three lines of piezo electric gauges (twenty-five observations per round).

The results from both sets of measurements are in satisfactory agreement and are summarised in Table 1, in terms of the performance of the Service $\frac{5}{16}$ inch steel cased bomb filled R.D.X./T.N.T. 60/40 = 100.

The observed values of blast impulse intensity have been used to obtain estimates of the areas over which buildings of typical German construction would be demolished or over which damage visible in aerial photographs would be caused.

In order to obtain a rough overall index of blast damage, the mean ratio for both sets of measurements and for both types of damage has been included in Table 1 as ' Mean Damage Area Ratio.'

For fillings of Minol 2 and R.D.X./T.N.T. 60/40 the mean damage areas for the aluminium alloy and $\frac{1}{8}$ inch steel bombs are 40–45 per cent. and 25 per cent. greater than for the same weight of filling in a Service ($\frac{5}{16}$ inch steel) bomb together with a reduction of total weight of about 600 lb. and 350 lb. respectively.

The mean damage area for an aluminium alloy bomb filled Minol 2 is nearly three times as great as that for a Service ($\frac{5}{16}$ inch steel case) bomb with the original filling of Amatol 60/40.

Conclusions

The use of bombs of increased charge/weight ratio, having either thin steel or aluminium alloy cases, results in an increased blast performance in close agreement with that estimated from previous results.

For a particular filling, a Bomb H.C. 4,000 lb. having a $\frac{5}{16}$ inch aluminium alloy case, weighs about 600 lb. less, and gives a mean area of damage about 50 per cent. more, than a Service bomb with $\frac{5}{16}$ inch steel case.

An aluminium alloy bomb filled Minol 2 gives a mean damage area nearly three times as great as that for a Service ($\frac{5}{16}$ inch steel case) bomb with the original filling of Amatol 60/40.

For a particular filling, a Bomb H.C. 4,000 lb. having a $\frac{1}{8}$ inch steel case weighs about 350 lb. less, and gives a mean area of blast damage about 25 per cent. more than a Service bomb with $\frac{5}{16}$ inch steel case.

Recommendations

The following recommendations are submitted :—

(*a*) That immediate consideration be given to the production of a Bomb H.C. 4,000 lb. with $\frac{1}{8}$ inch steel case for service use.

(*b*) That steps be taken to prepare a suitable production design of a Bomb H.C. 4,000 lb. with aluminium alloy case.

Table 1. Bombs H.C. 4,000 lb.

	Filled Weight. lb.		Impulse Ratio.		Demolition Areas.		Visible Damage Areas.		Mean Damage Area Ratio.
			A.R.D.	R.R.L.	A.R.D.	R.R.L.	A.R.D.	R.R.L.	
Steel, $\frac{5}{16}$ inch (Service) ..	4,020	R.D.X./T.N.T. 60/40	100	100	100	100	100	100	100
		Minol 2	106	105	115	115	108	111	112
Thin steel, $\frac{1}{8}$ inch ..	3,680	R.D.X./T.N.T. 60/40	111	110	125	119	127	123	124
		Minol 2	118	117	144	138	140	139	140
Aluminium alloy, $\frac{5}{16}$ inch	3,400	R.D.X./T.N.T. 60/40	117	119	135	140	156	146	145
		Minol 2	123	123	154	150	172	155	158

The values for Minol 2 (Service) are extracted from A.R.D. Explosives Report 68/44.

APPENDIX 7

PRECIS OF THE ORIGINAL PAPER ON DEEP PENETRATION BOMBS[1]

The argument

1. The bomb armament of all the belligerent Air Forces in this war consists of relatively small bombs designed to attack surface targets such as factories and houses.

2. This form of attack is effectively countered by dispersal. It is becoming impossible to destroy simultaneously all the factories and all the generating stations all over the Continent of Europe.

3. All these factories depend on few and highly localised stores of energy in the form of coal, oil and water power: air attacks on this country depend on large stores of petrol buried in tanks many feet underground.

4. These stores of energy are so concentrated and so massive that they cannot be dispersed, but also they are invulnerable to the present type of bomb armament.

5. The paper shows that :—

(i) These stores of energy are vulnerable to very large bombs.

(ii) By sterilising their stores of energy the industries of Germany and Italy can be quickly paralysed.

(iii) The very large bomb and appropriate bomb carrying aircraft are practicable and can be produced in this country.

These arguments led Wallis to formulate three axioms :—

(*a*) Modern warfare is entirely dependent on industry.

(*b*) Industry is dependent on adequate supplies of power.

(*c*) Power is dependent on the availability of natural stores of energy such as coal, oil and water.

In Chapter 1 Wallis expands these axioms, and shows that a new technique of air attack is required to destroy these natural sources of energy, against which 'experts have given the opinion that the existing equipment of the British or of any other Air Force is quite powerless to inflict any but minor and therefore repairable damage.'

Chapter 2 reviews the existing bomb armament and the methods of using it. Small bombs designed specifically for the attack of civil buildings, factories, bridges and railways by means of direct hits.

Chapter 3 deals with the 'destructive characteristics of a bomb', and defines the meaning of such terms as 'blast', 'pressure pulse' and 'gas bubble', showing the importance of pressure pulse as an agent of destruction. This pulse, a wave motion, Mr. Wallis shows to be much more potent than had been generally realised. It is the 'effective and deliberate use of this pressure pulse which in fact constitutes the new technique already referred to.'

Chapter 4 enlarges on the characteristics of wave motion derived from a spherical charge in a uniform medium and Chapter 5 deals with waves and structures. All arguments are founded on mathematical principles.

Chapter 6 sums up the conclusion to which the writer has been led by the preceding arguments. Massive targets demand a new technique in bombing, and this involves two departures from current practice ;

(i) The use of far larger units.

(ii) The use of pressure waves to destroy a surrounding medium, rather than the reliance upon a direct hit.

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[1] A precis of the paper by Mr. B. N. Wallis, entitled 'A Note on a Method of Attacking the Axis Powers' prepared in 1940. A.M. File C.S. 8640, Encl. 2B.

The choice is summed up in the following proposition :—

> 'To attack these targets successfully, it is necessary to inject the largest possible charge to the greatest possible depth in the medium (earth or water) that surrounds or is in contact with the target.'

Then follows Wallis's idea for the design of a bomb of high charge-weight ratio, of very large size for earth penetration, and for an aircraft to carry it. Calculations lead him to a weight of 10 tons, released from 40,000 feet, as likely to give the desired result. The bomb must be of modern high tensile steel. Such a bomb, in sandy soil, was calculated to reach a depth of 135 feet ; in such a medium the minimum depth for complete ' camouflet '—that is the formation of no crater, but the expenditure of all detonation energy in producing disturbances of a seismic character, was calculated to be 130 feet. Realising that the practical achievement of such a depth might not be easy, Wallis observed that no very great loss of seismic effort would occur provided detonation took place at depths below those at which the charge would be equivalent to a common mine—that is one in which the radius of the resultant crater is approximately equal to the depth at which detonation occurs. Wallis then examined mathematically the factors involved in designing a bomb for penetration to maximum depth.

Chapter 7 examines the whole problem of high altitude bombing from the points of view of technical ability with the apparatus then available, and opportunity. He envisaged a pressure cabin bomber which should at 40,000 feet be immune from attack, not only because of its height but because of its correct structure. Apart from the design of the aircraft, three major points arise :—

(i) The possibility of seeing the ground owing to cloud interference.

(ii) The smallest object which can be distinguished.

(iii) The accuracy of bombing.

The first problem has since been solved, or partially solved, by the use of Radar equipment. The second has been examined by Professor H. H. Plaskett who was led to the following conclusion :—

> ' In the absence of scattered light, a black test object two feet in width will be clearly visible against a white background from a height of 31,000 feet.'

The third problem is one involving the accuracy of bomb sights, and consistent ballistic properties in the bomb. With the stabilised automatic bomb sight, and the mathematically designed Wallis bomb, a bombing error of 40 yards per 40,000 feet was possible with specially trained crews. The Wallis principle did not demand a direct hit to destroy a target.

Chapter 8 deals with typical large targets—petrol and oil storage tanks, coal fields, oil fields, hydro electric dams, multiple arch dams and gravity dams, surface transport—and examined in detail the probable effect of earth shock on these. All arguments are amply illustrated by diagrams, the whole representing a monument of careful, concentrated work by a man already fully occupied with his own business of aircraft design.

APPENDIX 8

MR. WALLIS'S REPORT TO THE AIR STAFF, JUNE, 1943[1]

THE WEIGHT OF BOMBS IN RELATION TO THEIR TARGETS

1. Introduction

It is a truism that any target whatever can be destroyed or effectually damaged provided that the attacking charge is big enough to do the work, and can be placed and detonated within lethal range.

In spite of this there exist to-day in Germany a number of important key targets which have proved invulnerable to the blast bombs and incendiaries which form the standard equipment used by the R.A.F.

[1] A.M. File C.M.S. 80, Encl. 20A.

2. History

In the early stages of the war, the use of blast and fire offered a way of producing a powerful bomber force quickly. "Stick" and "Area" bombing eliminated the necessity of accurate aim, and avoided the delay involved in developing an accurate bomb sight, and attacks could thus be made in darkness with existing types of comparatively small, slow and lightly defended aircraft carrying a number of relatively light bombs, well within the contemporary development of H.E. charges; for at that time the belief was common that there was a limit to the weight of a single charge that could be successfully detonated.

Further, it was contended, and is still often maintained, that a large number of relatively light bombs are more effective than a small number of proportionately heavy bombs. This contention is true only as far as a particular type of target is concerned, namely large collections of light structural buildings such as factories and residential districts. It overlooks the factor of Size, Shape, and Situation of the target, which either singly or in combination may be such as to render a target invulnerable to any number of bombs that are below a certain weight of charge.

As a consequence we are still impotent against targets of vital importance to the maintenance of Germany's war effort. A few examples of such targets classified according to the characteristic that renders them invulnerable to the present equipment of the R.A.F. are given in the attachment to this Appendix. For convenience in this note we shall refer to these targets as 'S.I. Targets' *i.e.*, Size Invulnerable, Shape Invulnerable or Situation Invulnerable respectively.

The destruction or extensive damage of such targets depends upon the use of heavy bombs, of a size and shape adapted to the target.

3. The Operation of heavy bombs

It being granted that the lucky solution of a direct hit on an S.T. Target is outside the bounds of probability, there remain two ways in which heavy bombs can do their work:—(i) by the formation of large craters; (ii) by deep penetration into the earth, utilising the big earth movements caused by the tamped explosion, as the destructive agent. By this means, the 'lethal area' in which a bomb may be dropped and yet be effective, is very greatly extended.

(i) The formation of large craters

The tactical utility of the crater lies in the fact that it takes time to fill in, and the principal targets against which it can be used are those which are 'Shape-Invulnerable'. (*See* (*b*) of attachment to this Appendix.)

The invulnerability of railway lines, viaducts, bridges, canals and locks lies in their extreme tenuity, which renders them readily repairable after the very local damage caused by surface detonating bombs. So rapidly in fact can damage to railway lines be repaired, after attack by standard bombs even of the largest type, that this target, once regarded as of the greatest importance and frequently attacked, is now almost entirely neglected by the R.A.F.

The whole position must however be reconsidered when bombs can be made and carried that are capable of making craters so large that the estimated time for refilling is ten to fourteen days working twenty-four hours a day.

The volume of soil thrown out of a crater, and hence the weight, is directly proportional to the weight of charge exploded, the graph in Fig. 1 showing the relationship.[1]

The large charge, however, possesses an increasing advantage over the small with regard to the time which is required to refill the crater, owing to the fact that it is impossible to use more men or equipment than there is room for round the perimeter. The perimeter thus forms the unalterable boundary which limits the amount of power that can be employed. Assuming that every foot of perimeter is thus occupied, the ratio of the length of the perimeter to the volume of the crater determines the amount of 'Shovel Power' that can be brought to bear per ton of ejected material, and it is seen from the graph in Fig. 2 that the Shovel Power per

[1] *See* Ministry of Home Security Publication R.C. 344.

ton decreases quickly as the size of explosive charge rises. This fact, derived directly from the mensuration of the conical crater, seems to have been overlooked. It operates powerfully to increase the advantage of the large bomb over the small when delaying tactics are in question.

A graph showing the estimated time to refill a crater against the weight of explosive charge is shown in Fig. 3 the times being calculated on the assumption that the crater is formed in level ground and that refilling apparatus such as mechanical shovels, can be brought up from all directions and to the full capacity of the perimeter. The time taken to refill the crater made by one 10 ton bomb is seen to be nearly five times as long as the time taken to refill simultaneously the craters made by ten 1 ton bombs, assuming that an equal total weight of explosive is used in both cases, and that unlimited labour is available.

In order that a given weight of charge may be used to eject the greatest possible weight of soil it is necessary that the explosion should take place at a considerable depth below the surface, and so much information is now obtainable connecting size of charge, depth of explosion and size of crater that curves showing the effect of varying these factors are now available.[1]

The approximate depth at which an explosion should take place in order to produce the largest possible crater for a given weight of bomb, assuming 50 per cent. charge weight, is shown in Fig. 7 by the full line, and on the same graph the depth of crater formed as a result of the explosion is shown by a dotted line. It will be noticed that the depth of crater is substantially less than the depth of the explosion, this effect being due to the fact that much of the material thrown out falls back into the hole, with the result, which is illustrated in Fig. 5 for a crater formed by a 10 ton bomb, that there is between 20 and 30 feet of loose soil lying at the bottom. It follows that for destructive purposes, such as destroying foundations of bridges and large buildings, the full depth of crater to the base of the explosion chamber (*i.e.* 75 feet in the case illustrated in Fig. 5) may be taken into consideration, whereas for estimating time required to refill, the observed depth (45 feet in case quoted) should be taken.

No attempt has yet been made after 4 years of war to utilise this potent effect of deep penetration. The reasons for our failure to do so are threefold, for deep penetration can only be obtained by bombs of correct shape and great strength of casing, with a high cross-sectional density, and dropped from a sufficient height to enable them to attain the necessary velocity on striking. These factors are discussed more fully in connection with The Operation of the Large Bomb in Deep Penetration.

(ii) The use of large craters to destroy shape-invulnerable targets

The relative size of crater formed by a 10 ton penetration bomb on Shape Invulnerable targets, such as railways, viaducts and canals, is illustrated in Figs. 4, 5, 8 and 9, and it is evident that the mere size of crater renders it a very potent method of disabling or totally destroying large sections of such targets.

The point at which a railway line should be attacked does not lie on the level where the line could readily be diverted without troubling to refill the crater, but where the railway lies on a sloping face as illustrated in Fig. 4 ; the advantage of choosing such a point being that the line cannot be diverted and that the hillside embankment must be rebuilt in addition to the work involved in refilling the crater itself. Thus the time estimated for refilling on the level may be considerably extended.

The question as to whether large craters would be refilled or bridged by trestling a gap between 140 and 150 feet wide would actually take longer than refilling. This will be clear from Fig. 5 where the depth and extent of the soil disturbed by a 10 ton bomb are illustrated.[2] Any attempt to trestle would involve the driving of piles through the disturbed soil until a solid foundation was reached.

[1] Ministry of Home Security Publication R.C. 355 Addendum. 'Crater Dimensions,' by Major F. W. Anderson.

[2] Figures calculated from curves given in Ministry of Home Security Publication R.C. 344 Addendum.

It should be noted that craters of this volume cannot be formed by large light cased bombs as the depth at which the charge must explode in order to form the crater illustrated lies between 50 and 60 feet below the surface, and it has been necessary to produce the Tallboy type of high-tensile charge case to obtain the strength required for deep penetration.

The utilisation of the large crater to destroy the foundations of such targets as viaducts and bridges without the necessity of securing a direct hit, is a natural consequence to the development of the Tallboy bomb. The relationship between the size of crater from a 10 ton bomb and the all important viaduct of Bielefeld on one of the principal railways leading from the Ruhr Valley, is shown on Fig. 8, the viaduct itself having been missed by a distance of 50 feet. As this miss could occur on either side we have the effect that the width of the lethal band in which the viaduct can be completely destroyed is well over 100 feet, thus offering a target which cannot be missed by aircraft flying in the formation illustrated in Fig. 4. The small sketch inset in Fig. 8 shows the number of arches destroyed by a 50 feet miss, and clearly many months would be required to consolidate the ground and rebuild the large part of the viaduct thus demolished, when it is remembered that the destruction of a single pier in the Brighton-Lewes viaduct completely interrupted all traffic for five weeks, the rebuilding in permanent form of the single pier and its contiguous arches occupying four to five months.[1]

Similarly canals, particularly in embanked regions, can be effectively breached. It is well known that there are long strips of both the Dortmund-Ems and Mittelland Canals where the embankment reaches a height of 50 feet above the surrounding level, the relative size of canal and crater being illustrated in Fig. 9. Attempts to destroy these canals by surface detonating bombs dropped in the water have proved ineffective, but an entirely new technique of attack is opened up by the use of the deep penetration bomb forming a large crater.

It is fortunate that for tenuous targets of this type Range Error is of no consequence, but to cover Line Error an attack should be carried out by machines flying in echelon or spearhead formation at such a distance apart that the craters formed overlap in alignment. The attack should be made at such a height (that is any height above 20,000 feet) as to ensure the required depth of penetration to form the crater. Heights of over 25,000 feet have the added advantage of giving freedom from interference by ground defences.

Five machines flying in formation as shown in Fig. 4, effectively cover a band 600 feet wide. The mechanical imperfections of the latest type of bomb sight[2] are extremely slight ; when it is aimed and operated correctly the dispersion from 20,000 feet would be less than 80 feet, so that the formation shown ensures the certainty of a direct hit when the bombing is carried out by a crew properly trained for high altitude precision bombing. It is emphasized however, that to attain this degree of accuracy particular attention must be given to the aerodynamic design of the projectile, a factor which has hitherto been ignored by all bomb designers, with the possible exception of the Americans. The Tallboy series of bombs have been especially designed to give the highest possible degree of accuracy in trajectory.

(iii) The operation of the large bomb in deep penetration

The depth of penetration which a bomb of suitable strength and shape of case can achieve is not only dependent upon the height from which it is dropped but upon the cross-sectional[3] density of the bomb itself. When once the ideal geometrical shape for most accurate air flight followed by earth penetration is decided, the geometry of similar figures of equal density leads at once to the result that the cross-sectional density increases with size in the manner shown in Fig. 6. The average penetration attainable varies directly with cross-sectional density. The variation of average depth of penetration with weight of bombs when dropped

[1] ' The Engineer ' 17 December 1943, page 484-5, ' Repair of Bomb Damage to Railway Viaduct on the Southern Railway.'

[2] ' Bombing . . . The American Way.' ' Aviation ' August 1943, page 119.

[3] Cross-sectional density is defined as the total weight divided by the maximum cross-sectional area.

from a height of 2,000 feet in various soils is shown in Fig. 10. It will be seen that when operating from a given height there is a substantial advantage in favour of the large bomb when deep penetration is required.

The earthquake wave sent out by bombs exploding at or near their camouflet depths is capable of damaging subterranean targets situated at a considerable distance from the explosion, the maximum earth movement caused at various distances from a deep explosion being shown in relation to the weight of charge in Fig. 11.[1] This earth movement increases substantially in proportion to the weight of the explosive charge.

(iv) The use of earth shock waves to destroy size-invulnerable and situation-invulnerable types of targets

The attachment to this appendix, (*a*) and (*c*) give examples of S.I. targets which are either completely buried underground or the superstructure of which is of so massive or attenuated a nature as to be practically indestructible, in which case the deep penetration bomb forms the only possible method of attack.

An outstanding example of the latter type lies in the Rothensee Ship Lift which depends entirely for its working upon hydraulic caissons penetrating 240 feet into the ground. This Lift is illustrated in Fig. 12, the lethal area in which a 10 ton penetration bomb can drop and cripple the hydraulic caissons being indicated in the plan. Anything short of a direct hit from a very large bomb could cause no substantial damage to the superstructure of this Lift, consisting as it does of heavy steel members, and in the event of such a lucky hit, the damage would no doubt be speedily repaired. The only method of putting this key target out of operation for a long period lies therefore in destroying or jamming the hydraulic floats below ground. It is fortunate that the ground in which these shafts are sunk is particularly suitable for deep penetration, and in addition, being waterlogged, serves to transmit the earthquake wave to the greatest possible distance.

The mechanism of the Lift is such that the trough and its contents are held in exact equilibrium by the upwards reaction of the totally immersed air filled floats which have a displacement of 2,700 tons each. The raising and lowering mechanism is only sufficiently powerful to overcome frictional forces introduced by sluice gates and guides, being otherwise designed to hold the Lift in any required position ; and it is only necessary to produce a sufficient distortion in the relatively thin concrete lining of the hydraulic shafts to prevent the free rising and falling of the float, and thus to put the Lift out of action for an indefinite period. When dropped from a height of 20,000 feet, Tallboy Large should enter soft waterlogged ground to a depth equal to nearly half the depth of the shafts. The upper ends of these shafts are embedded in the concrete foundations of the Lift and cannot, therefore, partake of the maximum horizontal earth movement which will be caused by a bomb exploding approximately 100 feet below the surface, and it is probable, therefore, in this case that the shafts will be fractured, and possibly displaced at the upper end. There is, however, a further effect to be considered in the almost instantaneous rise of pressure in the shaft with the possibility of damage to the float.

Experiments which have been carried out by the Ministry of Home Security[2] give some indication of another use of Tallboy Large for the destruction of railway tunnels where the cover or amount of ground above the tunnel is not too deep. Fig. 13 shows that where the depth of cover is less than the maximum lethal radius, the width of the lethal band within which the bomb will damage the tunnel is not sensitive to the depth of penetration, but that at depths greater than the lethal radius, penetration must occur directly above the tunnel to ensure severe damage. In no case can a tunnel be damaged where the depth of cover is equal to or greater than the lethal radius of the bomb plus the depth of penetration ; a matter of about 200 feet in clay or 150 feet in hard chalk for bombs equal in size to Tallboy Large.

Fig. 14 shows the length of tunnel affected by a 100 feet miss with a tunnel 100 feet underground.

[1] Ministry of Home Security Publication R.C. 263, 'A Survey of Information on the Action of Bombs Exploding in Earth.' D. G. Christopherson, D.Phil., page 2.

[2] Ministry of Home Security Publication R.D. 262 'Notes on the Siting and Construction of Air Raid Shelter Tunnels.' Captain F. W. Anderson, pages 14 and 15.

ATTACHMENT TO APPENDIX 8

S.I. TARGETS

EXAMPLES OF VITAL TARGETS THAT ARE INVULNERABLE TO THE STANDARD EQUIPMENT OF THE R.A.F.

(*a*) Size—Invulnerable

1. The Rothensee Ship Lift.
2. The Sorpe Dam and other earth type Dams.

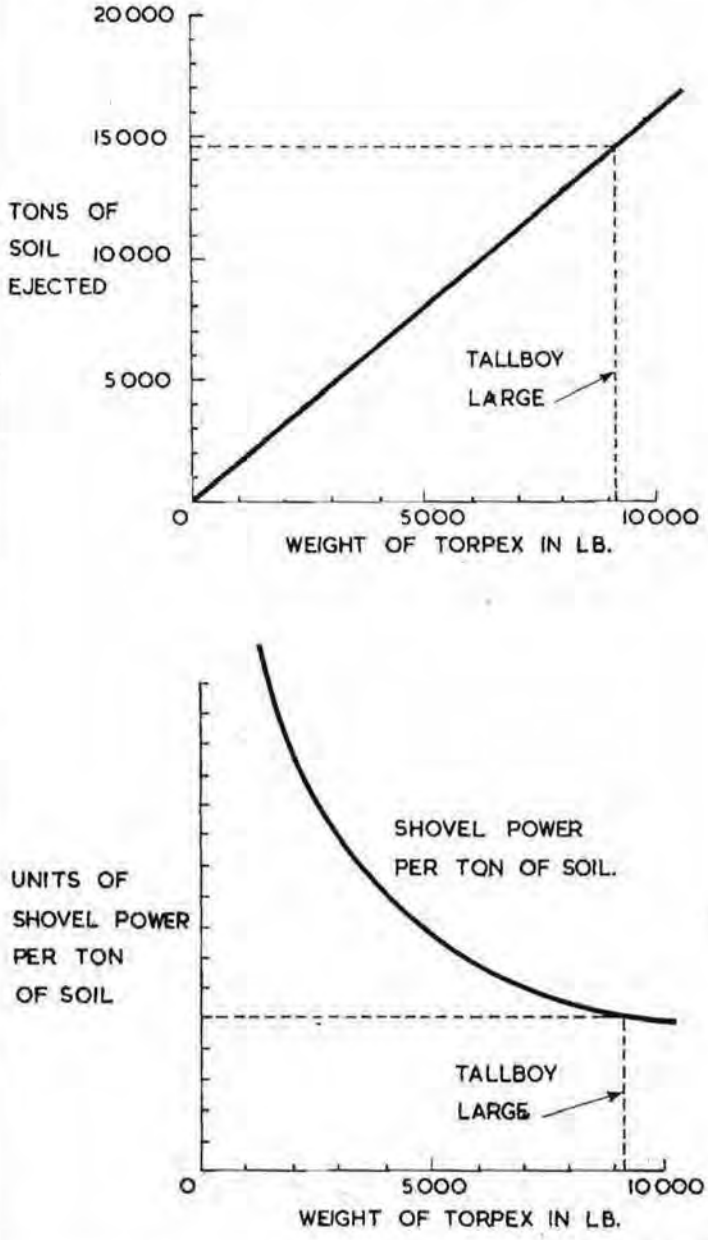
(*b*) Shape—Invulnerable

1. Railway lines, Viaducts and Bridges, notably the Bielefeld, and other viaducts which command the whole traffic east of the Ruhr Valley.
2. Canals and Locks, such as the vital Dortmund-Ems, and Mittelland Canals

(*c*) Situation—Invulnerable

1. All subterranean targets such as Railway Tunnels, Tube Railways, Deep Sewers, Buried Oil Storage.
2. All Vertical Shafts, such as Coal Mine Shafts, and the great hydraulic Balance Shafts of the Rothensee Ship Lift.
3. The Foundations of Bridges, Viaducts, Aqueducts and large Structures in general.

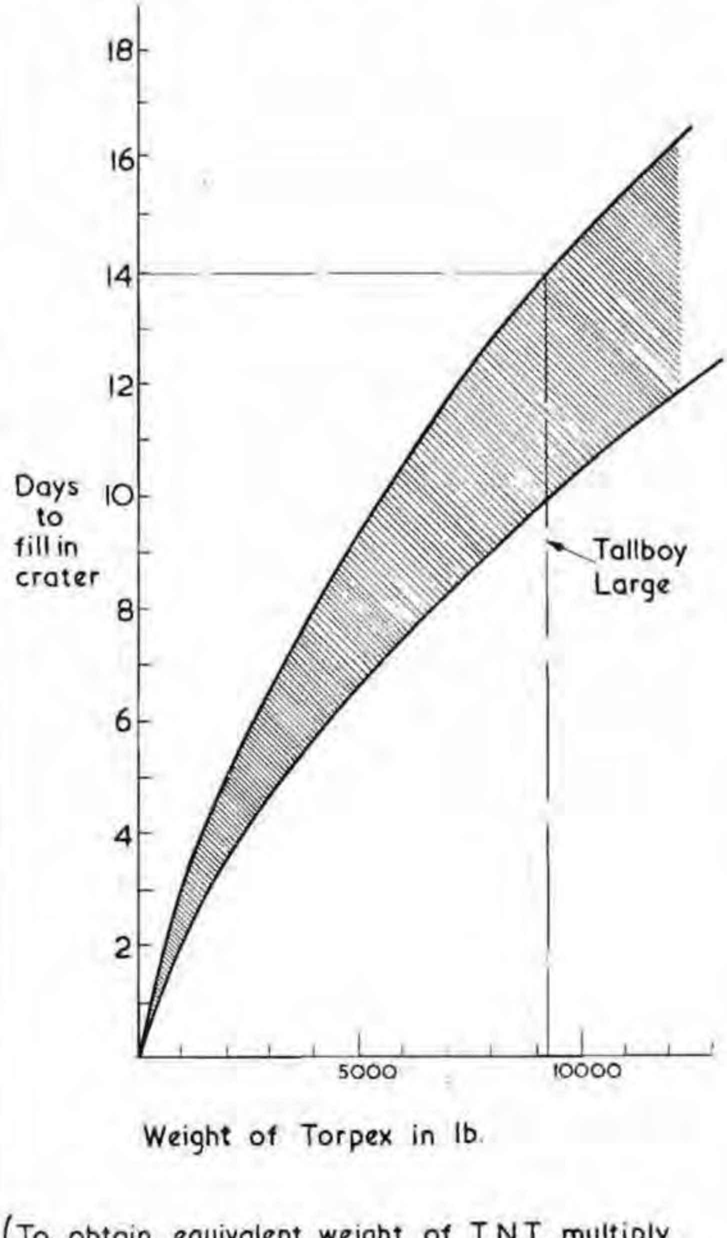
CURVES SHOWING HOW WEIGHT OF SOIL EJECTED AND SHOVEL POWER PER TON OF SOIL VARY WITH WEIGHT OF CHARGE



FIGS. 1 & 2

AHB.I. DIAG. NO. 294.

CURVE SHOWING HOW TIME TO FILL IN CRATER VARIES WITH CHARGE WEIGHT



(To obtain equivalent weight of T.N.T. multiply weight of Torpex by 1·4)

Fig. 3

AHB1 DIAG. NO. 281

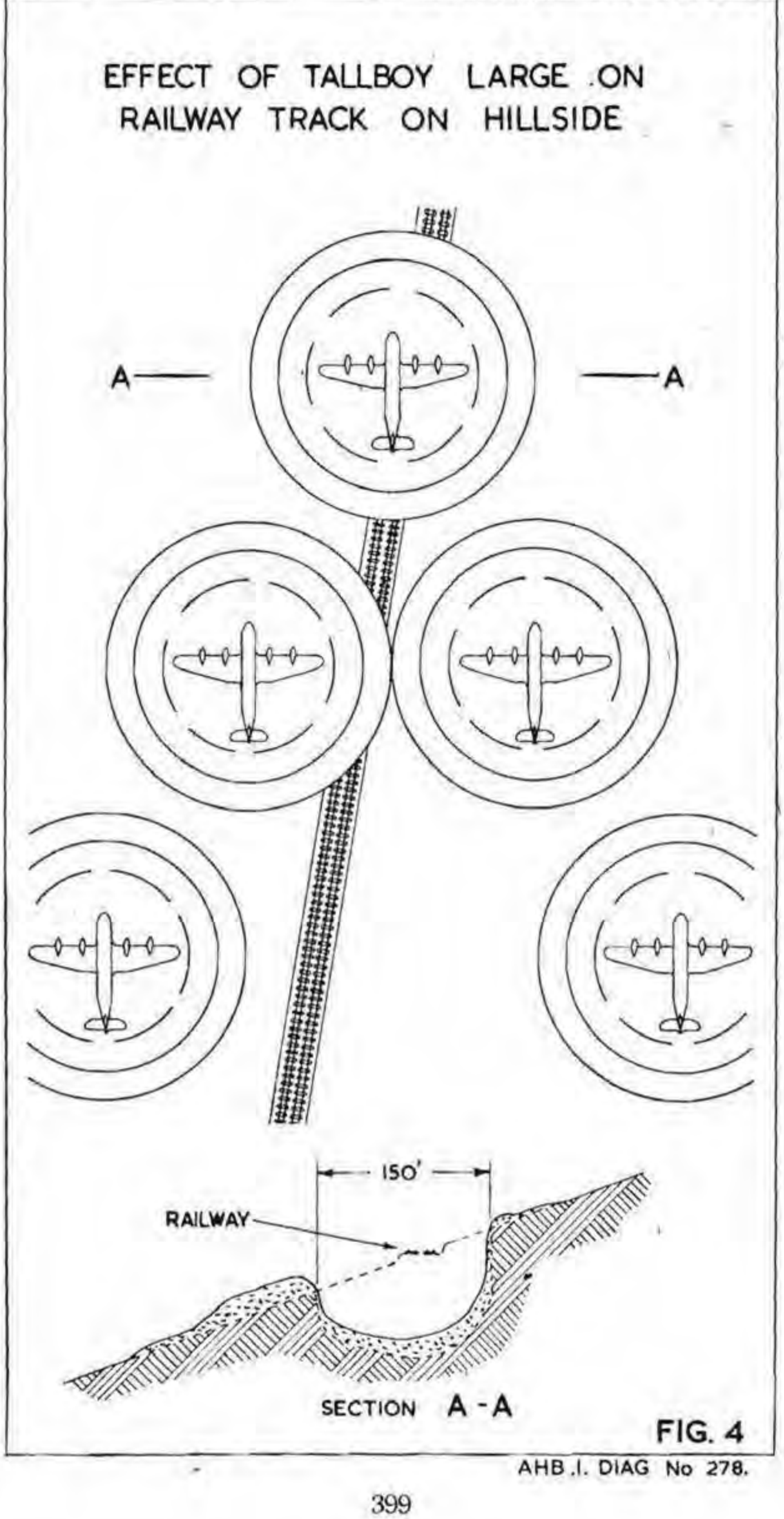


FIG. 4

AHB.I. DIAG No 278.

ATTACHMENT TO APPENDIX B

APPROX. SHAPE OF THE CRATER MADE BY A TALLBOY LARGE

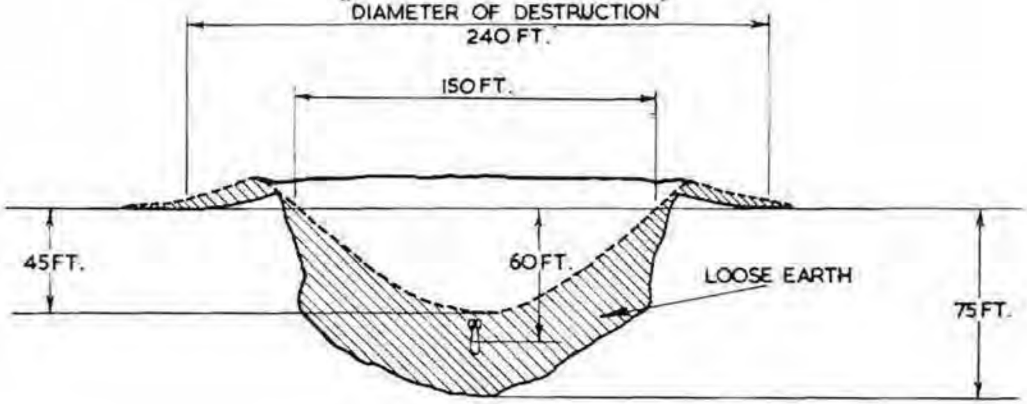
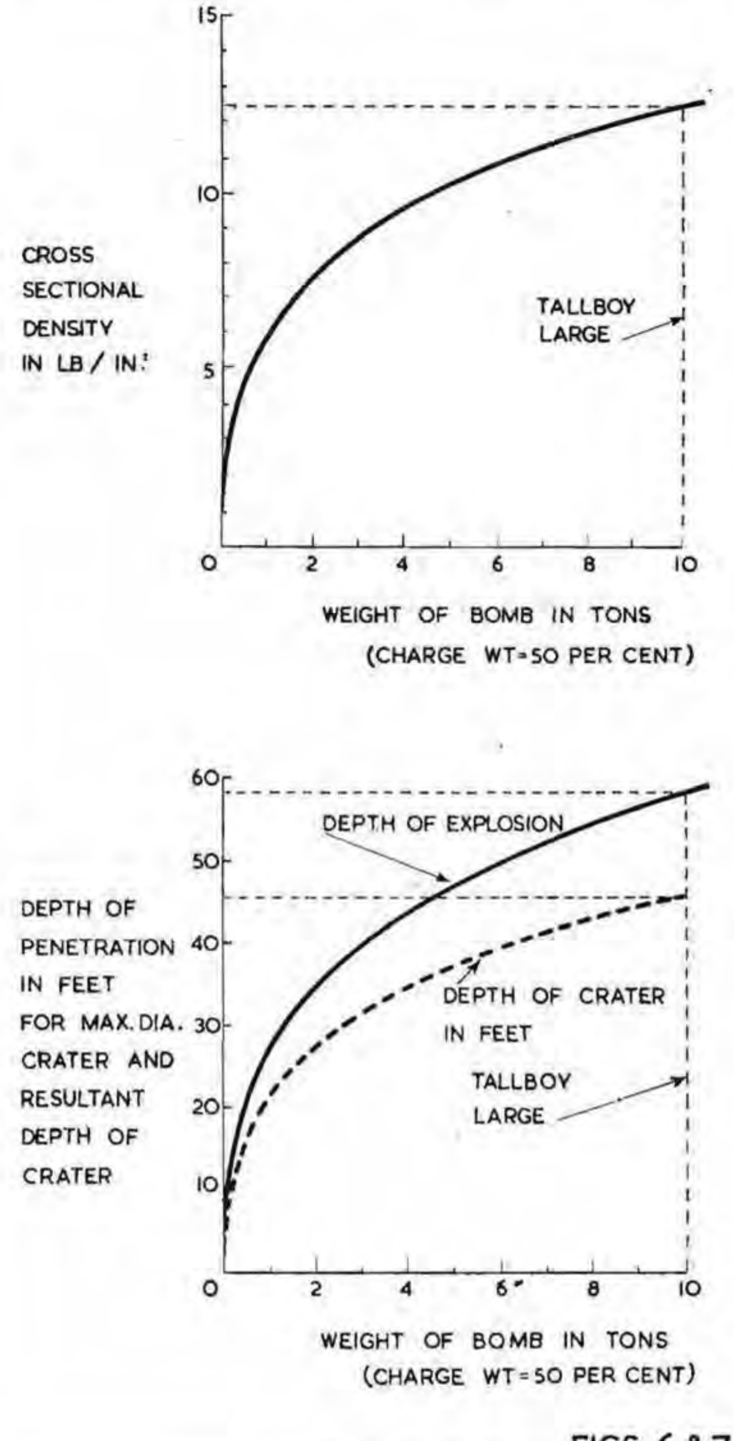


FIG. 5

A.H.B. DIAG. No 274



FIGS. 6 & 7

AHB.I. DIAG. NO 293.

EFFECT OF 50FT. MISS ON BIELEFELD VIADUCT WITH TALLBOY LARGE

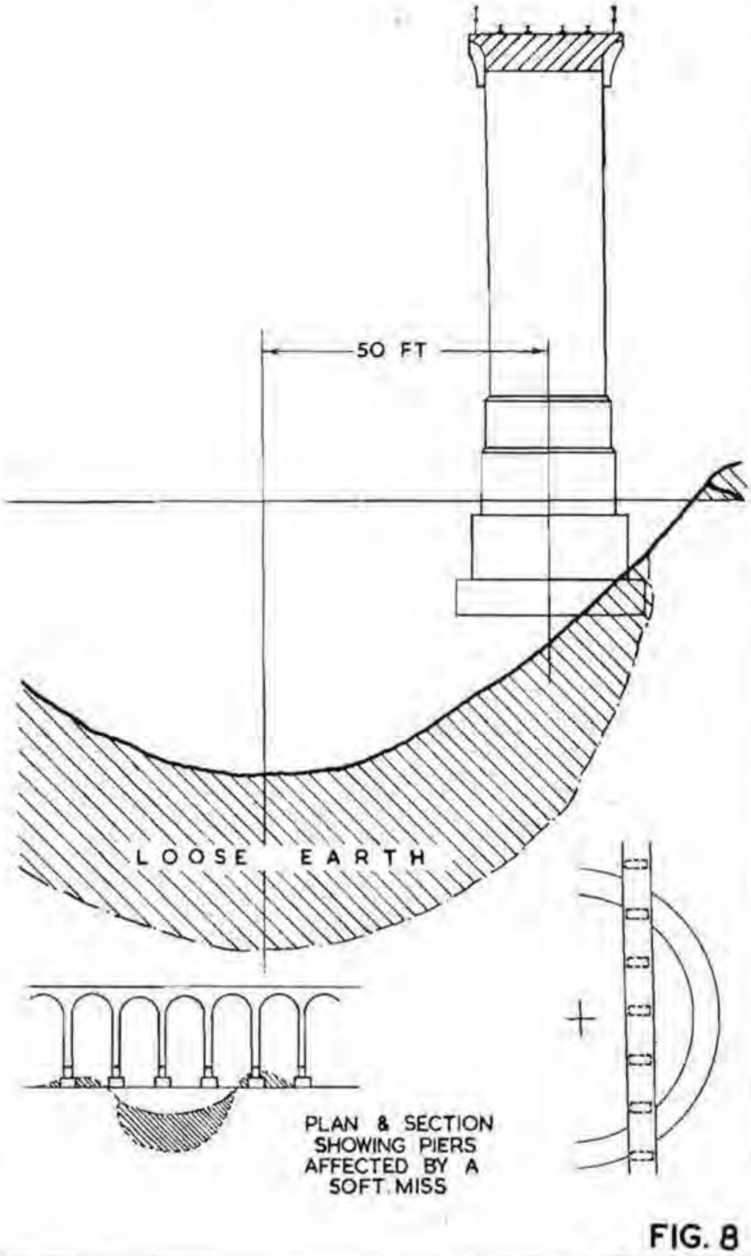
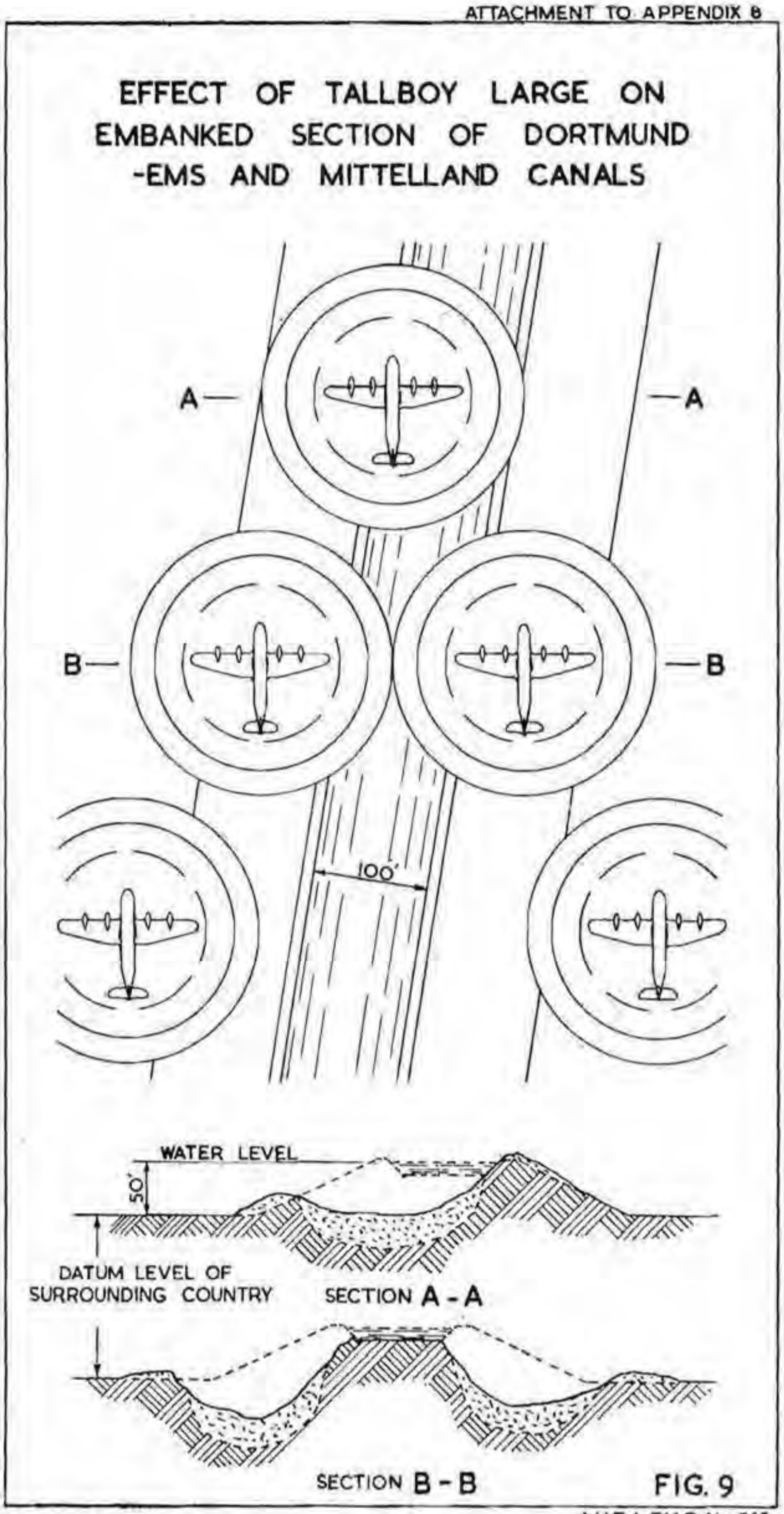


FIG. 8

A.H.B. DIAG. No. 275.

ATTACHMENT TO APPENDIX 8



A.H.B.I. DIAG No 265

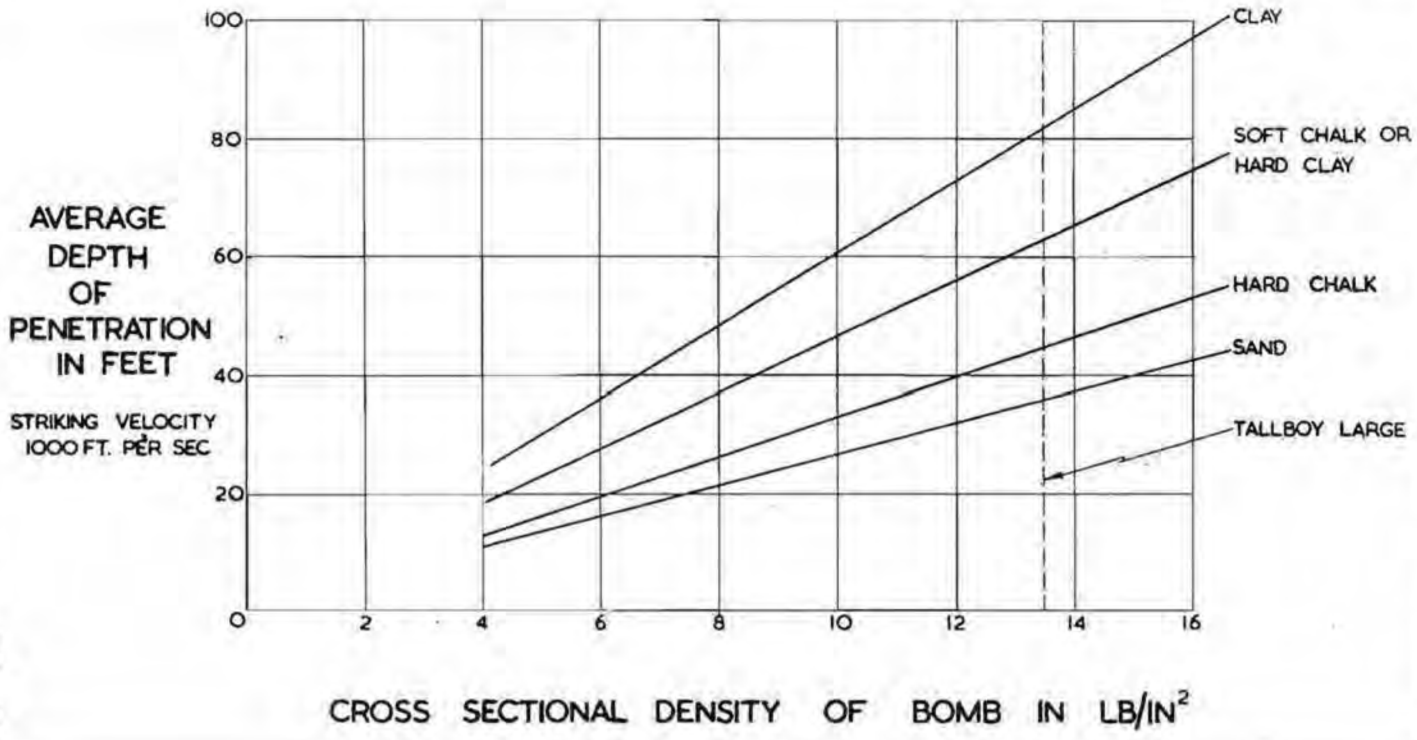


FIG. 10

A H B DIAG No 273

CURVE SHOWING HOW MAX. HORIZONTAL EARTH MOVEMENT VARIES WITH WEIGHT OF CHARGE AND DISTANCE FROM THE EXPLOSION

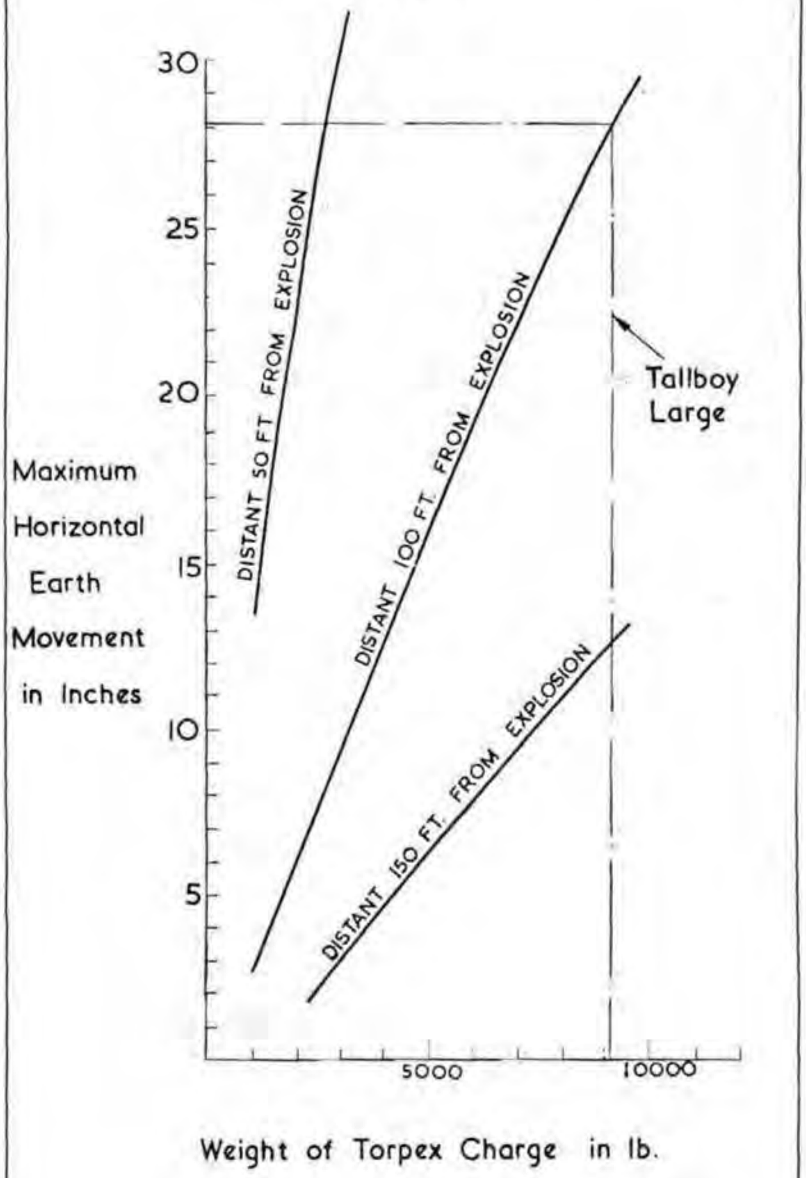
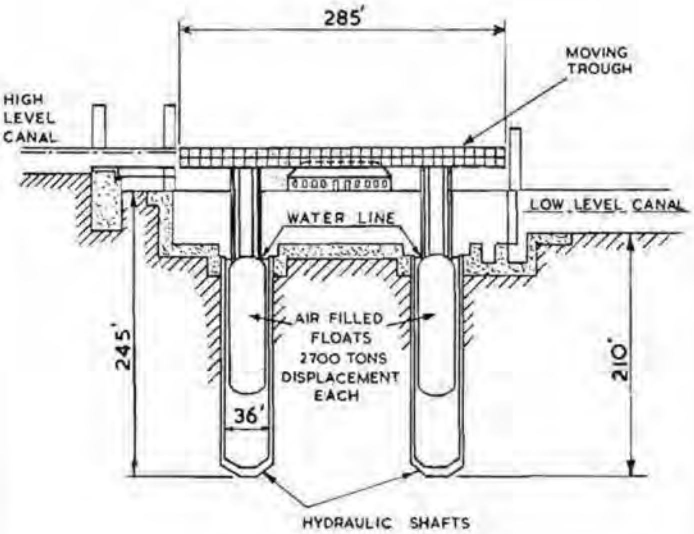


Fig. 11

A.H.B.I DIAG NO 282

ROTHENSEE SHIP LIFT



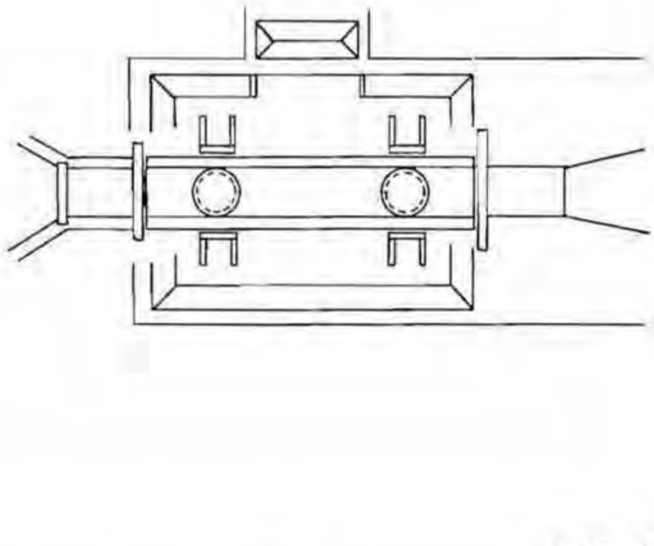


FIG. 12

AHB.I. DIAG. NO. 295

WIDTH OF LETHAL BANDS FOR AN ATTACK ON TUNNEL WITH TALLBOY LARGE

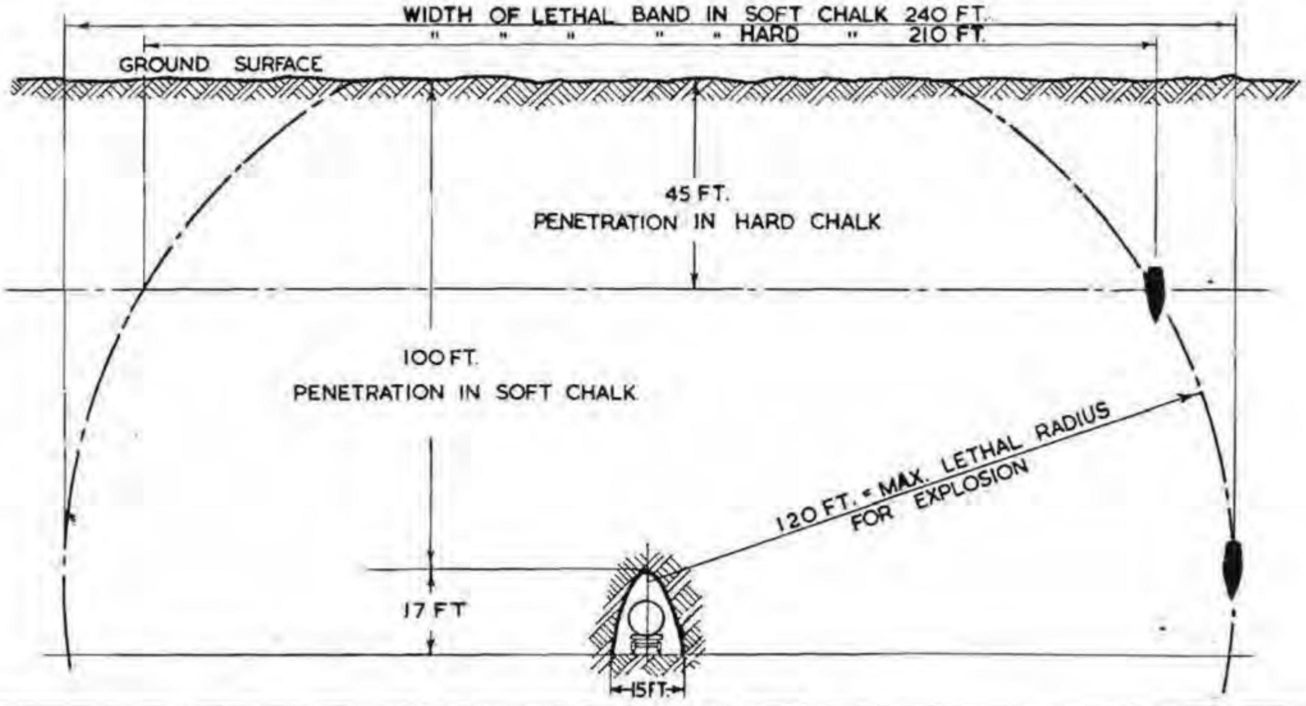


FIG. 13

A.H.B. DIAG. No 276

ATTACHMENT TO APPENDIX 8

PLAN VIEW SHOWING EXTENT OF DAMAGE TO TUNNEL RESULTING FROM 100 FT. MISS WITH TALLBOY LARGE

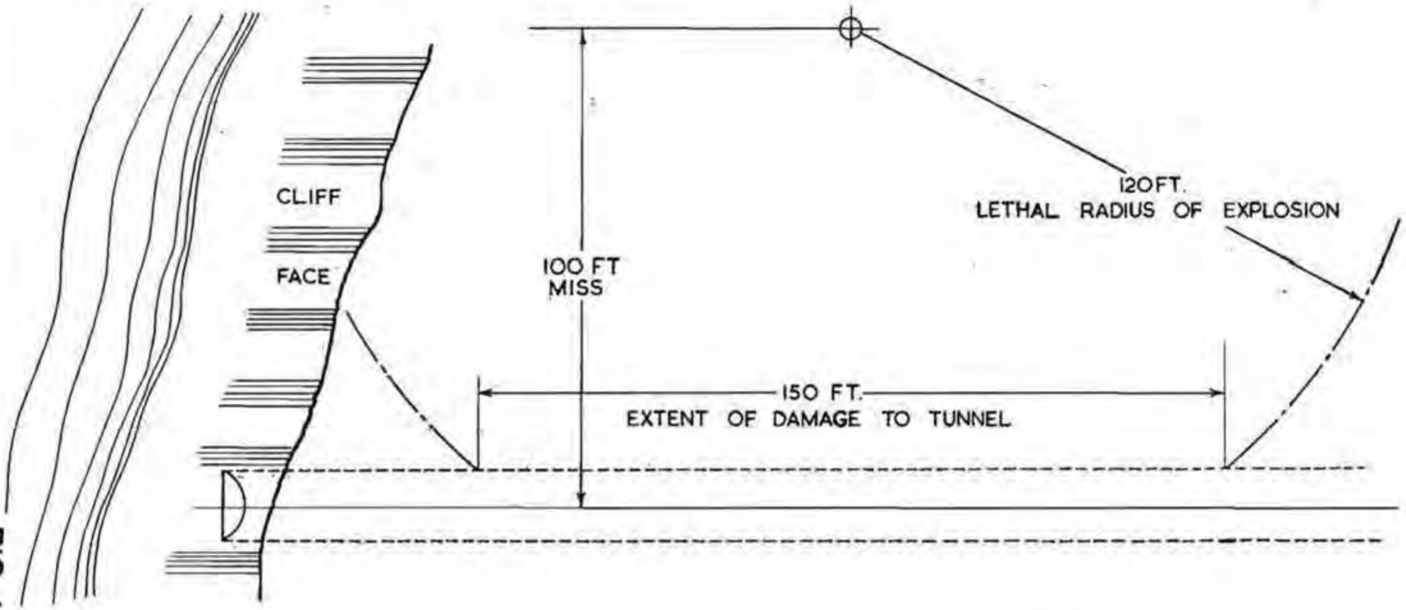


FIG. 14

A.H.B. DIAG. No. 277.

ATTACHMENT TO APPENDIX 8

APPENDIX 9

MANUFACTURE OF CHROME/MOLYBDENUM CAST STEEL

ENGLISH STEEL CORPORATION LIMITED, VICKERS WORKS, SHEFFIELD

METALLURGICAL AND RESEARCH DEPARTMENT

Tallboy (Medium) in 3 per cent. Cr/ Mo. Steel

27 October 1943

Composition

The steel, which should preferably be made in the basic electric furnace, should have a composition with the following range :—

Carbon	0·28 to 0·32
Silicon	0·35 max.
Manganese	0·50 to 0·70
Nickel	0·50 max.
Chromium	3·20 to 3·50
Molybdenum	0·50 to 0·55

Procedure after casting

The casting should be allowed to cool slowly in the mould in order to allow the thermal transformation to take place in the pearlitic range. The range of temperature over which the cooling rate is particularly critical is 850/700° C., and if this range is traversed sufficiently slowly the casting will be perfectly soft when it is stripped. If possible, readings of the temperature should be taken with a thermo-couple in order to determine the natural cooling rate in the mould employed.

If a suitable annealing furnace is available for rapid charging of the casting after stripping, the latter operation can be done at a temperature of about 500° C. at the head portion of the casting where the section is heavier. If such a furnace is not available it would be preferable to allow the casting to cool to about 300° C. at the head portion before stripping. In either case, however, the casting should be charged as soon as possible into a furnace standing at about 300° C. in the case of the casting which has cooled down to this temperature in the mould, and about 400/500° C. with the casting which has been stripped at the higher temperature previously referred to. After charging, the furnace with the casting should be raised to a temperature of 700/730° C. and then allowed to cool slowly after an adequate soaking period.

Removal of head

After the treatment of 700° C. described previously, the head of the casting should be burnt off at a point some inches ahead of the finish machined portion and before becoming cold the remainder of the casting should be charged into an annealing furnace and raised slowly (about 30/40 degrees per hour) to a temperature of 1,000° C, soaked until uniform, and then cooled slowly, especially through the range 850/700° C., so as to permit transformation in the pearlitic range. The range of cooling over this temperature range should be approximately 10° C. per hour, and after reaching 700° C., this cooling rate may be accelerated to that of normal furnace cooling down to a temperature of 300° C. where the casting may be withdrawn from the furnace and cooled in air.

Final heat treatment

For this process the casting should be carefully supported so that any tendency to sag is reduced to a minimum. The casting should be heated to a temperature of 900° C., soaked until uniform and then withdrawn and allowed to cool freely in air down to a temperature of about 200° C. On reaching this temperature the casting should be recharged for tempering, for which purpose a temperature of about 730° C. should be satisfactory to give the required tensile strength of 45/50 tons/square inch. A suitable rate of heating for both hardening and tempering is about 30/40 degrees per hour, though in the case of the hardening temperature this rate may be accelerated.

APPENDIX 10

OPERATIONAL RESEARCH SECTION (B.C.) **REPORT No. S.218**

THE RESULTS OF ATTACKS WITH 12,000 LB. M.C. (TALLBOY) BOMBS

1. This report has been prepared in response to a particular request for a statement on attacks with 12,000 lb. M.C. (Tallboy) bombs covering the following points :—

(i) Numbers dropped on individual targets by day and by night classified by types of target.

(ii) Fuzing.

(iii) Bombing height.

(iv) Type of bombsight used.

(v) Accuracy.

(vi) Results of attacks.

(vii) A general appreciation of the value of the weapon.

Items (i) to (iv) and also a brief statement of Item (vi) are given in the Appendix in which the data for each attack are listed separately. The period covered is from the first attack on 8/9 June 1944, when the target was the Saumur Railway Tunnel, up to the end of March 1945. A summary of the number of bombs dropped on each type of target during this period is given in Table I below :—

Table I

Summary of Tallboy Operations

Type of target.	*Number of bombs dropped.* *By day.*	*By night.*
Shipping and Naval Installations	76	29
Tunnels	nil	30
Large V-weapon Sites	107	nil
Submarine and E/R-boat Pens	182	22
Viaducts and Bridges	160	nil
Dams and Aqueducts	65	24
Synthetic Oil Plant and Oil Storage Depots	15	11
Total	605	116

2. On most land targets an 11-second delay detonator has been used, but on some occasions ½-hour or 1-hour delay pistols were employed in order to obviate obscuring the target by smoke. Owing, however, to a rather unsatisfactory design of the ½-hour delay pistol some of the bombs so fuzed gave premature detonations on soft targets. A 0·5-second delay fuze was also used in a small number of attacks on heavy reinforced concrete structures. For attacks on shipping a 0·07-second delay or a 0·5-second delay fuze have been used.

3. The bombing heights have varied widely but, the great majority of the attacks have taken place between 11,000 feet and 18,000 feet.

4. All the earlier attacks were made using the S.A.B.S. Mark IIa, a tachometric bombsight, but a second squadron equipped with the Mark XIV Bombsight, a vector sight, began to operate with these bombs in September 1944, and since then both types of sight have been used.

Accuracy—Night

5. The only night attack for which accuracy figures are available is that on the Saumur Tunnel on 8/9 June 1944, when 18 bombs were aimed at the South entrance of the tunnel. In this attack the bombsight used was the S.A.B.S. Mark IIa and the heights of bombing were between 8,000 feet and 10,500 feet. One bomb was a gross error of 680 yards and the remainder had an average error of 115 yards from the Aiming Point. Further details are given in O.R.S. (B.C.) Report No. S.161.

Day

6. In a series of daylight attacks carried out between 19 June 1944 and 13 August 1944, using the S.A.B.S. Mark IIa in which the bombing took place from heights between 16,000 and 18,000 feet, 24 per cent. of the bombs dropped were gross errors. The remainder had an average error of 170 yards. An analysis of a further number of attacks from those made in the period December 1944 to March 1945, using the S.A.B.S. Mark IIa, indicated that the gross error rate had fallen very considerably and was then less than 5 per cent. A firm estimate is difficult to make since it is probable that there are a greater proportion of gross errors among the unplotted bombs (10 per cent. of the whole number) than among those whose craters have been plotted on reconnaissance photographs. The remainder have an average radial error about the Aiming Point of 125 yards. In this series of attacks the heights of bombing varied from 9,000 to 18,000 feet with an average of about 13,000 feet.

7. An analysis has also been made of a small number of daylight operations in February and March 1945, in which 12,000 lb. M.C. (Tallboy) bombs were dropped using the Mark XIV bombsight. In these the bombing height again averaged about 13,000 feet but the range of heights was much smaller, and the percentage of gross error was 10–15 per cent. Again only a tentative estimate can be made since the proportion on photographic cover is uncertain. The average radial error of the remainder is 195 yards. Errors in wind estimation are one of the principal reasons for the bombing accuracy being considerably less with the Mark XIV than with the S.A.B.S. Mark IIa.

8. The information on accuracy given in the preceding paragraphs is summarised in Table II below :—

Table II

Accuracy of Tallboy Attacks

	Average Radial Error.	*Percentage Gross Error.*
S.A.B.S. Mark IIa, June–August 1944	170 yards	26
S.A.B.S. Mark IIa, December 1944–March 1945	125 yards	2–5
Mark XIV, February–March 1945	195 yards	10–15

Results of attacks

9. A brief summary of the results of each attack are given in the Appendix. The main points of interest are the effect of the bomb on the massive reinforced concrete structures such as submarine pens and the large V-weapon sites, on viaducts and large bridges, and on the *Tirpitz*.

10. The 12,000 lb. M.C. (Tallboy) bomb was not designed for attack on very hard targets but for the production of large craters and maximum earth shock by deep penetration into the ground with a large charge. Nevertheless the cast steel body is capable of withstanding impact against very heavy targets and the bombs will cause a penetration of reinforced concrete roofs as much as 18 feet 6 inches thick. Such penetrations are, however, made by the blast of the explosion and the bomb itself will not penetrate more than 6 feet to 8 feet before exploding. As a result, collapse of massive reinforced concrete structures or even of parts of them has only rarely been achieved and the damage within has been confined to that caused by the falling masses of concrete blown out of the roof by the explosion. It is noteworthy that all the serious damage to the large V-weapon sites was caused by very near misses in which the structure was undermined by the crater. At the Brest submarine pens where there has been a comprehensive ground survey, it was found that the loading cranes over some of the pens and the electric cables were disrupted by this type of damage and the mechanism of the door of one of the pens was put out of action.

11. It appears that the Torpex filling used is too sensitive for use against very hard targets and there have been a number of cases of pre-initiation in hits on such targets for this reason and also in some cases there may have been telescoping of the body. It would appear that for such targets a forged bomb with less sensitive filling is necessary.

12. Very near misses up to 20 feet to 30 feet have been extremely effective in breaching viaducts since they have not only cut the spans but also destroyed piers almost completely, thus making repair very much more difficult. Attacks on bridges have also been very successful in causing damage so serious that repair would be very difficult. In one case, Bad Ceynhausen, a near miss at 50–60 feet distance was sufficient to cause collapse.

13. The *Tirpitz*, a modern capital ship which had been designed to make it as nearly unsinkable as possible, was capsized and sunk by an attack with these bombs in which it is estimated that three direct hits and two–three near misses were scored. This fact illustrates the power of this bomb against heavily armoured ships and shows that they can be sunk by it provided hits can be achieved. In a more recent attack the pocket battleship *Lutzow* was sunk by a near miss at approximately 60 feet.

14. The average size of the craters in normal soil is 97 feet in diameter and about 25 feet in depth measured from the level of the loose filling on the bottom to the rim. Most craters are between 90 and 105 feet in diameter and between 17 feet and 35 feet in depth.

Appreciation of the 12,000 lb. M.C. (Tallboy) bomb

15. This bomb is a specialized weapon which can at present only be dropped in small quantities. Its value is therefore determined by the importance of the special targets for which it alone is suitable and is dependent also on the ability to drop it with great accuracy. This latter condition has been achieved in Bomber Command by the use of highly trained specialist squadrons for the purpose. The specialized targets for which it has shown itself to be a completely effective weapon are :—

Capital ships.
Viaducts and large bridges.
Tunnels with up to about 50 feet of overburden.
Reinforced concrete roofs up to about 10 feet thick.

Against structures which have a thicker reinforced concrete roof a bomb capable of penetration before explosion would do a much greater degree of damage. It is probable that the 22,000 lb. (Grand Slam) M.C. has a considerable advantage over the 12,000 lb. (Tallboy) M.C. in this respect, but there is not yet sufficient evidence available from its operational use to determine to what extent this is so. The sensitivity of the Torpex filling will, however, detract from the potential performance of the bomb against such targets. Nevertheless, there is no doubt that attacks with the 12,000 lb. bomb interfered with the use of submarine pens and also at least caused serious delays in the construction of the large V-weapon sites. These sites were abandoned following the attacks with this bomb but to what extent the ground situation contributed to this decision is at present uncertain.

16. Targets for which the 12,000 lb. M.C. (Tallboy) or the 22,000 lb. M.C. (Grand Slam) are the most advantageous weapons or the only ones suitable are those which can be penetrated by these bombs, but not by those of smaller calibre, *e.g.* capital ships.

SUMMARY OF 12,000 LB. H.C. (TALLBOY) ATTACKS BY NIGHT

1. Shipping and Naval installations

Date.	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Result.
31/1.1.45	Shipping in Oslo Fjord ..	10	0·5 secs.	7,000–12,500, S.A.B.S. ..	Not known.
6/7.3.45	Sassnitz, Naval installations	19	0·07 secs.	3,500–12,500, Mark XIV	Not known.

2. Tunnels

Date.	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Result.
8/9.6.44	Saumur tunnel	19	0·025 secs.	8,400–10,500, S.A.B.S. ..	Craters average 84 feet diameter, 25 feet depth. One fell on the tunnel roof, 30 yards from entrance and caused roof to collapse.
4/5.7.44	St. Leu d'Esserent, underground storage depot.	11	11 secs.	16,500–19,000, S.A.B.S.	No bombs located on the target.

3. Submarine and E.R. boat pens

Date.	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Result.
14/15.6.44	Le Havre, E-boat pens ..	22	0·5 secs.	15,500–19,000	One bomb caused a penetration and a break in the top of the north wall.

4. Viaducts and bridges—nil

5. Dams, dykes and aqueducts

Date.	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Result.
23/24.9.44	Ladbergen, canal aqueduct	6	½ hour	14,000, S.A.B.S., and Mark XIV.	Embankments breached.
3/4.3.45	Ladbergen, canal aqueduct	18	½ hour	8,000–14,000, Mark XIV	Not known.

6. Synthetic oil plants

Date.	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Result.
21/22.12.44	Politz, Hydrierwerke Politz A.G.	11	11 secs.	15,000–20,500, Mark XIV	Not known.

SUMMARY OF 12,000 LB. H.C. ATTACKS BY DAY

1. Shipping

Date.	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Results.
15.9.44	*Tirpitz*, Kaa Fiord (near North Cape).	15	—	17,500 - 11,350 S.A.B.S. Mark XIV	Smoke screen. No serious damage claimed or observed. (Damage was, in fact, so serious as to render movement to Germany for major repairs impossible, and consequently the ship was moved to Tromso for duty as a ' floating fort.')
29.10.44	*Tirpitz*, near Tromso ..	32	—	12,000 - 16,000 S.A.B.S. Mark XIV 19 a/c. 19 a/c.	No serious damage.
12.11.44	*Tirpitz*, Tromso Fiord ..	29	0·07 secs.	12,500 - 16,500 S.A.B.S. Mark XIV 18 a/c. 12 a/c.	Ship capsized and sunk by 3 direct hits and 2–3 very near misses.

2. Large V-weapon sites

19.6.44	Watten	17	11 secs.	15,500–18,000, S.A.B.S.	No damage.
24.6.44	Wizernes	16	11 secs.	16,500–17,500 S.A.B.S.	A bomb in the north quarry caused a big landslide of the quarry face, completely blocking the railway track and south tunnel entrance.
25.6.44	Siracourt	16	11 secs.	16,000–19,000, S.A.B.S.	Section of overhanging roof 100 feet by 15 feet broken off by very near miss.

Date	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Results.
6.7.44	Mimoyecques	14	11 secs.	16,000-19,000, S.A.B.S.	Bomb against corner of main construction exploded under the wall, destroying a corner of the concrete platform 63 feet by 35 feet. The crater was approx. 35 feet deep and 100 feet in diameter. At the bottom of the crater a cavity extended beneath the platform. Further damage to this target was noted during a visit to the site at the end of hostilities. The southern shaft was covered in by a near miss ; whether by this or some other Tallboy raid is unknown.
17.7.44	Wizernes	16	11 secs.	16,600-18,600, S.A.B.S.	Part of chalk cliff collapsed and the fall of rock completely blocked four of the tunnel entrances.
25.7.44	Watten	16	½ hour	17,000-18,500, S.A.B.S.	Direct hit caused severe damage to main T-shaped structure, cutting out semi-circular portion roughly 38 feet across and 17 feet in radius. Large area of concrete blasted from N.E. edge of rectangular reinforced concrete building.
31.7.44	Rilly La Montagne, Ministry construction.	12	½ hour	16,700-17,000, S.A.B.S.	Not known.

3. Submarine pens

Date	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Results.
15.6.44	Boulogne	11	0·5 secs.	7,500-18,500, S.A.B.S.	Pens not hit.
5.8.44	Brest	14	11 secs.	16,500-18,500, S.A.B.S.	Six craters on roof of pens. One penetration of the roof achieved.
6.8.44	Lorient	11	11 secs.	16,000-18,000, S.A.B.S.	Three craters on roof of pens. No penetrations.
9.8.44	La Pallice	12	0·5 secs.	16,500-18,000, S.A.B.S.	Six direct hits, large parts of concrete in S.E. corner dislodged. Large area of roof near centre torn up.

3. *Submarine Pens.—contd.*

Date.	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Results.
12.8.44	Brest	8	0·5 secs.	16,000–18,000, S.A.B.S.	Three hits on roof. One probable penetration. Another broke off a piece of overhanging roof 10 feet by 15 feet by 12 feet.
18.8.44	La Pallice	6	0·5 secs.	16,000–18,000, S.A.B.S.	No appreciable damage.
24.8.44	Ijmuiden	8	11 secs.	16,000–18,000, S.A.B.S.	Two direct hits. One penetration. Other has caused a piece of the roof at the edge, 95 feet by 33 feet, to break away. Near miss appears to have partially undermined corner.
15.12.44	Ijmuiden	13	11 secs.	9,000–10,000, S.A.B.S.	Part of roof, 140 feet by 33 feet, over four pen entrances has collapsed as result of one or two hits. Parts of roof seen to be sagging. Another hit has caused a possible penetration.
29.12.44	Rotterdam	16	11 secs.	16,000–18,000, S.A.B.S.	Section of roof over entrance, approx. 158 feet by 20 feet, has been destroyed.
12.1.45	Bergen	24	6 at 0·5 secs. 18 at 11 secs.	14,500 – 18,000 S.A.B.S. Mark XIV 16 a/c. 16 a/c.	Three or four direct hits. A gap about 25 feet in diameter torn in edge of one section.
3.2.45	Poortershaven	18	0·5 secs.	13,000–14,000, S.A.B.S.	Severe damage or virtual destruction of all buildings.
3.2.45	Ijmuiden	17	½ hour	14,000–17,000, Mark XIV	No damage.
8.2.45	Ijmuiden	15	½ hour	14,000–17,000, S.A.B.S.	One direct hit destroying uncompleted portion of roof over three pens.
27.3.45	Farge	4	1 hour	14,000–19,000, S.A.B.S.	Two penetrations of roof but possibly due to 22,000 lb. M.C. which were also dropped.

4. Viaducts and bridges

Date.	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Results.
22.2.45	Bielefeld	18	11 secs.	12,500–14,500, S.A.B.S.	Two piers of one viaduct destroyed by near miss.
22.2.45	Altenbeken	16	11 secs.	12,000–14,000, Mark XIV	One span destroyed.
13.3.45	Arnsberg	1	11 secs.	12,500, Mark XIV ..	No damage.
14.3.45	Bielefeld	13	11 secs.	16,000–12,000, S.A.B.S.	Seven spans of each viaduct now destroyed (three of one viaduct had been previously). No trace of five piers of one viaduct. Stumps of five piers of other viaducts are all that remain. Some of this damage may be due to one 22,000 lb. M.C. bomb.
14.3.45	Arnsberg	15	11 secs.	12,000–14,000, Mark XIV	Direct hit at tunnel entrance brought down roof and blocked lines which were also cut by crater.
15.3.45	Arnsberg	6	11 secs.	13,000–14,000, Mark XIV	Not known.
19.3.45	Arnsberg	12	11 secs.	11,000–13,000, S.A.B.S.	Two spans collapsed and embankment undermined. 22,000 lb. M.C. bombs were also dropped and may have caused some of the damage.
19.3.45	Vlotho (Bridge)	15	11 secs.	11,000–13,000, S.A.B.S. and Mark XIV.	Bridge damaged by near miss at 60 feet.
21.3.45	Arbergen (Railway Bridge)	17	11 secs.	13,000–14,000, S.A.B.S.	Viaduct breached for 180 feet (two spans). One span destroyed by one or two near misses. Adjoining section thrown off piers by near miss. Two 22,000 lb M.C. bombs may have contributed to damage.
22.3.45	Nienburg (Railway Bridge)	12	5–25/30 secs. 7—1 hour.	9,000–10,000, S.A.B.S. ..	All three spans broken or torn off piers. Five 22,000 lb. M.C. bombs probably contributed to damage.
22.3.45	Bremen (Railway Bridge)	14	50 per cent. —1 hour. 50 per cent. —25/35 secs.	15,000–20,000, Mark XIV	No damage by 12,000 lb. M.C. bombs which all missed.

4. *Viaducts and Bridges—contd.*

Date.	Target.	Number Dropped on Primary Target.	Fuzing.	Height of Release (feet) and Bombsight.	Results.
23.3.45	Bremen (Railway Bridge)	11	50 per cent. —1 hour. 50 per cent. —25/35 secs.	16,000–18,000, S.A.B.S.	One span collapsed by near miss close to river bank, 22,000 lb. M.C. bomb may have been responsible.
23.3.45	Bad Ceynhausen (Railway Bridge).	10	5—11 secs. 5—25 secs.	12,800–13,900, Mark XIV	Both parallel halves of bridge collapsed by near miss at 50 feet–60 feet.

5. Dams, Aqueducts

7.10.44	Kembs (Dam)	11	High—·025 Low—½ hr.	600 ft. and 6,000–8,500, S.A.B.S.	One span of barrage destroyed by direct hit.
15.10.44	Sorpe (Dam)	16	12—11 secs. 6—½ hr.	13,000–15,000, Mark XIV	Two direct hits on Dam did not breach it.
8.12.44	Urft (Dam)	3	11 secs.	6,500–12,000, S.A.B.S. ..	Dam not hit.
11.12.44	Urft (Dam)	35	11 secs.	4,500–10,000, S.A.B.S. and Mark XIV.	Dam not hit.

6. Oil storage

27.3.45	Farge	15	½ hour	15,500–17,000, Mark XIV	Results not known.

APPENDIX 11

THE R.A.F. RAID ON THE MÖHNE DAM, 16/17 MAY 1943

Text of two German official reports on the raid and its effects.

Report from the Regierungspräsident, ARNSBERG, WESTPHALIA, to the Minister for Home Affairs. Dated 24 June 1943.

In the night of 16/17 May 1943 an air raid warning was sounded at 00.23 hours. At about 00.30 hours–00.45 hours the Möhne Dam, which was protected by six 2 cm Anti-Aircraft guns, was attacked by enemy aircraft with large calibre bombs. There was no balloon barrage and the attack was carried out from a very low level. A number of bombs fell into the reservoir immediately in front of the Dam, thereby weakening the structure and probably causing a number of fissures. A further bomb hit the Dam itself and aided by the pressure of the contained water mass made a breach 76 metres wide and 21–23 metres deep. It is now impossible to ascertain whether this breach was caused by the bomb itself, or whether the original hole was later enlarged by the escaping water.

An immense floodwave poured through the Dam into the Möhne and Ruhr valleys. The main wave, carrying about 6,000 cubic metres of water at a height of 8 metres (up to Neheim), reached a speed of more than 6 metres per second. Below Lake Hengstey it still had a speed of 3 metres per second and then slowly spent itself. At 07.30 hours, 1,500–2,000 cubic metres per second were still flowing through the Dam.

The warden of the Dam, Oberfoerster Wilkening, had a direct line to the exchange at Soest and a tie-line to the Dam itself and the man on duty there. This line was tested every night according to instructions and was found on the night in question to be in perfect order. During the raid, however, the terminus at the Dam was destroyed by a direct hit and this put the main line to Soest out of order. After wasting precious minutes trying to get through to Soest, Oberfoerster Wilkening finally ran to the station of the Ruhr-Lippe Railway and got through from there via Koerbecke. According to a statement by Post Office officials, this call was received between 01.10 and 01.15 hours. Between 01.30 and 01.35 hours a second report, warning of an impending flood catastrophe, was received. Before that nothing was known here of the two calls of the Oberfoerster.

The Post Office was hindered in its work by the fact that the electric light had failed and candles had to be used. Officials tried to ring through to Neheim via Menden. They were unsuccessful, because the line Soest–Menden, or more probably Menden–Neheim, was already under water. Exact details cannot be established now. The vehicle and driver, on duty for just such an emergency, were unable to transmit the warning further downstream, since the roads had already been flooded with incredible speed.

The enemy air raid lasted until 03.23 hours, despite A.A. fire, but no further damage was caused.

According to instructions laid down, Regierungsdirektor I (Niewiesch) had gone to the Town Hall as soon as the low-flying aircraft indicated a serious attack on the town of Arnsberg near the dam. He got to his post at 00.30 hours and satisfied himself that all the emergency services were operating according to plan. When the report from Soest of the damage to the Möhne Dam was received at 00.50 hours, he immediately ordered the Police at Neheim to be notified and then the Police stations in the towns further downstream. The warning was actually received in Neheim before the arrival of the floodwave, but since, owing to the air raid warning, most people were in their shelters, it was almost impossible for the police to warn the population effectively and in time.

As I was on duty in Berlin at the time, the Regierungsdirektor, after ordering the warning to be passed on, notified my deputy of the occurrence. He than requested immediate help from the Army. After doing that, he went to the Dam to inspect the damage on the spot. The troops which had been asked for arrived in Neheim at 05.00 hours although they had had to arrange transport first. The police reinforcements which we had asked for also turned up quickly.

The party arrived at the Dam at 01.20 hours and found the telephone destroyed as reported. They tried to issue warnings from the neighbouring Möhnessterassen Hotel, but were unable to get through. The waterworks engineer, who was one of the party, then asked to be taken to the flooded areas. This took some time, since by then most of the recognised roads had been cut. They finally arrived at Neheim at about 03.00 hours and found the Council assembled in a high-lying building which had become the headquarters of the rescue services. All the local officials and the Deputy Gauleiter arrived almost immediately. Everything possible had been done, and the organisation was running as smoothly as could be expected.

As soon as I myself returned from my duty journey, I, in conjunction with the Reich Defence Commissioner, took all measures that became necessary, as the situation developed.

If, in the course of investigation, the question of the efficacy of the warning system is raised, the following observations should be noted.

Whatever the warning system employed, material damage could not have been minimised except in a very small way, such as for example the driving of cattle on to high ground. Houses, factories and installations could not have been moved, although a small number of valuables might have been evacuated. The very regrettable loss of human lives could hardly have been avoided in the danger zone because of the size of the breach and the tremendous speed with which the dammed-up water was released. The casualties in areas further removed from the scene of the catastrophe were, in the circumstances, unavoidable, but had the warning system been speedier some lives may have been saved. Any shortcomings in the warning system must be attributed to the failure of the competent authorities to give us correct information as to the possible effects of enemy bombs. Had we been informed that there was a possibility of the enemy using bombs of such weight, we should have realised that the existing warning system was inadequate and our technicians would have concentrated on devising a more effective system. Alternatively, the danger area could have been evacuated for the duration of the war.

Immediately after the catastrophe, I went into the matter with a Post Office engineer, who made the suggestion that a cable should be embedded in the structure of the Dam itself, which would, in the event of that structure being affected or agitated, automatically transmit a warning. This would be immediate and all human error would be cut out. The details are not ready yet, as there are difficulties with the supply of materials and laying of the wires. Meanwhile, local warning systems have been installed at all dams in such a way that the population would, in an emergency, have sufficient time to save themselves. The development of a perfect system is having constant consideration.

Report from the Regierungsprasident, Arnsberg, to the Minister of Labour. Dated 22 June 1943.

Results of the raid

Damage to river and riverbeds : The bed of the Möhne and the Ruhr is silted up below Neheim and has moved in many places, the river having changed its course slightly. The Möhne, from the Dam to where it flows into the Ruhr, and the latter up to 1·5 km. below that point, will have to have its banks completely reconstructed. Below Neheim, in the ' Ohl ', large gravel banks have been formed and are cutting off the valley. They hinder the drainage of the floodwaters and are the reason why large areas of the Möhne valley are today still flooded. The so-called Mill—or Upper Canal, which branches off from the Möhne above Neheim and supplies water to a number of industrial concerns and to the hydro-electric installation of the firm F. W. Broeckelmann, is completely silted up. Works dependent on this water supply are therefore idle.

Damage to Hydro and Electric installations : On the Möhne, the power station Möhnesee—capacity 120,000 kVA (kilovolt-amperes)—has been completely destroyed, including the compensating reservoir. All large machinery, with the exception of a transformer which was recovered 100 m. downstream, has disappeared. The small power station situated further south is so heavily damaged that it will probably be impossible to repair it again. Heavy damage has also been caused to the water-works at Schulte in Guenne, Hennecke in Himmelpforten and those of the Vew with a transformer station in Niederense and of the firm of Broekelmann in Neheim. The buildings and plant of the small power station Möhnesee have remained intact. In the Ruhr valley, the power station of the water-works at Echthausen has escaped structural damage, but the weir and mechanical installations have been destroyed. At Wickede, weirs have been destroyed at the local power station, the Soest water-works, and the Vereinigte Stahlwerke (Steel Works), and also at the local power station at Froendenberg, where large portions of the banks of the Upper Canal have caved in. The dam of the water-works at Gelsenkirchen in Langschede has been similarly destroyed. The Hengsen weir of the Dortmund water-works and the power installation Westhofen of the same company have also been badly damaged. In all these cases, works of great economic importance are involved.

The dams of the Ruhrverband on the Hengsteysee, by the Stiftmuehle between Hengstey and Harkotsee and the power installations on the Harkotsee have also been damaged due to mud, silt and the undermining of its structure.

The water-gauge installations at Neheim, Froendenberg, Echthausen and Villingst have suffered fairly heavy damage.

The following damage was caused to overhead and underground electric cables :

100 kV Overhead cable Unna–Neheim destroyed for 3 km.
25 kV Overhead cable Froendenberg–Neheim destroyed for 3 km.
10 kV Overhead cable Niederense–Honningen destroyed for 2 km.
10 kV Overhead cable Echthausen–Bremen destroyed for 2 km.
10 kV Underground cable Niederense–Volbringen destroyed for 1 km.
25 kV Overhead cable Neheim–Möhne power station is destroyed in a number of places, altogether for about 2 km.

All the lines mentioned above have now been repaired. Supplies of electric power have been resumed with the exception of the line Neheim–Möhne power station, which is still under repair.

The local circuits at Guenne, Niederense, Neheim–Huesten I, Vosswinkel and Echthausen have also suffered considerably, the stations in their area having been damaged and silted up.

Damage to water-works and purification plant : The water-works of the town of Neheim-Huesten, situated in the Möhne valley, which served the whole town district of Neheim, have been completely destroyed. A second works, further downstream has also been put out of action. That part of the town which is affected is being supplied from Huesten by means of a temporary pipeline, laid above ground.

The water-works along the Ruhr, *i.e.*, Gelsenkirchen, Hamm and Dortmund as well as those at Hagen, Witten and Bochum have already been reopened, after flood damage had been repaired, and are now in a position to supply, quantitatively, the most urgent needs of the area. As the quality is uncertain, chlorination has been ordered, and the population told to boil all water before use. The water-works supplying the towns of Soest and Gelsenkirchen have both been put out of action.

Of the purification plants, those at Neheim and Froendenberg have been rendered unserviceable.

Damage to railways : The main line Hagen–Kassel is heavily damaged between Neheim and Wickede and slightly damaged between Wickede and Froendenberg. The lines were in places completely undermined and at Wickede both rails had been lifted bodily off the embankment and washed on to a lower-lying field. Traffic has been resumed for local trains since the 8 June and for express trains since the 11 June. The southern part of the station at Froendenberg and the branch line to Menden have been completely wrecked. On the line from Wetter to Witten, one rail has been undermined in parts.

The narrow gauge railway Ruhr–Lippe has not been able to resume operations on the Möhne valley line. The rails from about 1·5 km. above the station at Niederense to the Mossfelde estate some way below have been washed away or covered in mud.

Damage to bridges and roads : All road and narrow-gauge railway bridges have been destroyed in the Möhne valley. The work of reconstruction has been taken in hand. In the Ruhr valley, the following damage has been reported : The road bridge by House Fuechten is threatened by high water but not damaged otherwise. The two at Neheim have completely disappeared. Of the ferro-concrete bridge, not even the piles have remained. The upper part of the iron bridge has been washed 100 m. downstream and deposited in the river bed. Of the railway bridge above Wickede the flood bridge and that over the upper canal have been destroyed and the bridge over the Ruhr heavily damaged. At Wickede the road bridge has been completely destroyed, likewise the road and the railway bridge of the Froendenberg-Menden line. The flood-bridge at Lengschede has been destroyed and the foot bridge is threatened by high water and damaged. The road bridge in Giesecke is slightly damaged, that over the Mill channel more heavily. The road bridges at Schwerte and Westhofen are also threatened by high water and damaged. One of the supporting pillars of the railway viaduct over Lake Harkort has collapsed.

The damage to roads varies from the appearance of pot holes to the complete destruction of the road bed and surface. The worst damage occurred to a stretch of road in Wickede.

Damage to industrial undertakings : Numerous industrial installations have been hard hit as a result of the attack. In many cases materials, buildings and machinery have been swept away by the floodwaters or damaged extensively by mud. Also they have been hindered indirectly by the damage to electric and water supplies. Worst hit of all were the firms situated in the lower Möhne valley around Neheim.

The camp for workers from the East, which had been erected for the Neheim industries at a cost of nearly a million marks, has completely disappeared. A number of factories further downstream have been damaged too and have had to suspend production, but I have not included them in my survey, since their damage consists less of that caused to buildings, as loss of tools, machinery and stocks of material. I will however mention the steel works at Hagen-Kabel and the steel works Harkort-Eicken in Wetter. In both cases the smelting ovens and rolling mills were working at full pressure when the disaster occurred and damage was so heavy that it cannot yet be assessed.

Damage to dwelling houses : The local Councils have reported the following damage :

KREIS	*Destroyed*	*Heavy damage*	*Medium damage*	*Slight damage*
Arnsberg	40	9	20	117
Soest	37	20	30	98
Iserlohn	2	28	48	48
Total	79	57	98	263

The largest areas of devastation are in Neheim and Wickede, where many houses were so completely washed away, that only the remains of the lower walls can be seen to show where they stood. Some houses have been only half carried away whilst many are still intact apart from the roof, which has disappeared. Most of the houses in question were massive structures with double walls. On the other hand, in Niederense some quite flimsy wooden buildings have withstood the flood waters and are intact right up to the second floor.

Agricultural damage : The 'Kreisbauernfuehrer' (local farmer leaders) report the following agricultural damage :

In Kreis Arnsberg 386 hectares of arable land and about 100 hectares of park, horticultural or woodland were flooded, making a total of about 486 hectares.

20 per cent. of the wheat, barley and corn crop is totally destroyed, and of the rest only a maximum harvest of 30 per cent. can be expected. The root crop has been completely destroyed. 40 hectares of arable land have been laid waste through loss of the top soil.

In Kreis Soest 280 hectares are completely and 153 hectares partially destroyed, as well as about 4 hectares of woodland.

In Kreis Iserlohn, one farm was completely and one partially destroyed.

According to present estimates, the following losses of livestock were suffered :—

KREIS	*Horses and Cattle.*	*Pigs*
Arnsberg	155	51
Soest	245	360
Iserlohn	86	115
Total	486	526

Dark as the picture of destruction may seem, it is a pleasure to note with what vigour peasants and farmers address themselves to the task of clearing their land of the accumulated rubbish and re-ploughing their fields.

Casualties : Our investigations into the exact number of deaths have not yet been completed as may be seen from the number of missing. The picture on 1 June was as follows :

	GERMANS		*FOREIGNERS*	
KREIS	*Dead*	*Missing*	*Dead*	*Missing*
Arnsberg	160	34	557	155
Soest	224	32	—	—
Iserlohn	49	—	6	—
Total ..	433	66	563	155

The heaviest losses of life occurred in Neheim and Wickede. The rescue and identification service was handicapped by the fact that the bodies were covered in mud, badly mutilated and had, in the hot weather, rapidly decomposed. Rapid burial was insisted upon to avoid the danger of epidemics. In actual fact no such outbreaks have been reported.

Emergency services : At first the emergency services were under the direction of the Councils of the three districts concerned. I personally took command of the situation on 25 May. In order to meet the immediate public emergency, strong military and civil help was organised. In the town of Neheim for example, the following personnel were employed up to the 22 May :—

1,250 military personnel.
380 men of the technical emergency service.
42 men and 60 women of the Red Cross.
150 men of the fire service.

Outside the town, the railways have mobilised some of their own manpower with the help of the R.A.D. (Labour Corps) and Pioneer Units. Detachments of the Organisation Todt were utilised for bridge and road repair and for work in connection with the rebuilding of purification plant. According to the Group Leader of the O.T. about 2,000 men would be required for the rebuilding of the dam itself. The Council at Arnsberg estimates the labour requirements as follows : 800 as replacement for the drowned personnel, 700 for clearance work and 200 for rebuilding. In addition, 300 men would be needed for the repair of water-works, water system, roads and houses, making a total of 2,000 in all.

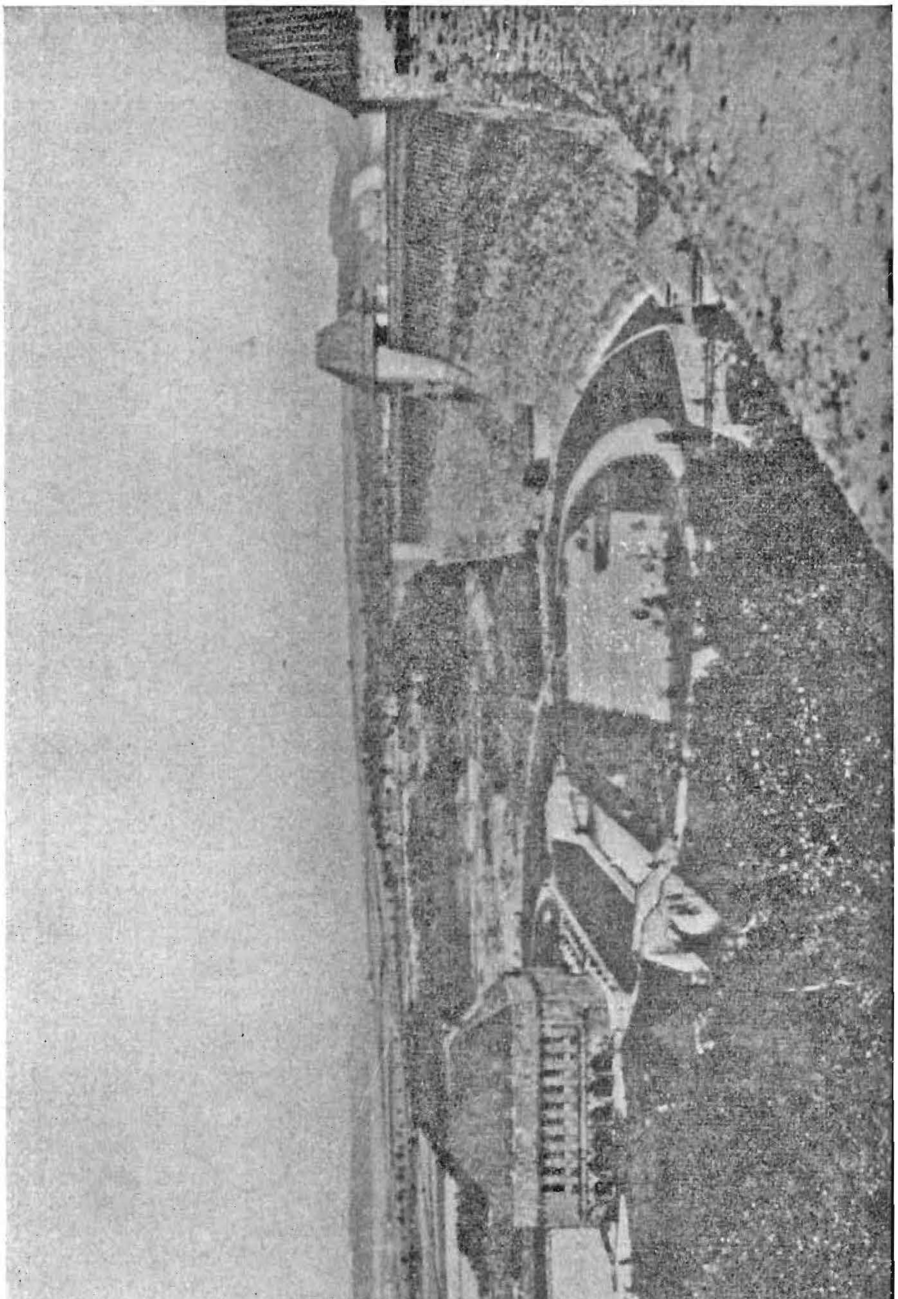
Estimates from the other Councils have not yet been received.

As has been said, and can be seen from the above survey of the damage caused by the disaster, industrial and agricultural undertakings have been badly hampered in their production for a shorter or longer period, as the case may be. This was occasioned through the damage sustained by water and mud. Apart from that, water-works, power stations, etc., have been made unserviceable, either permanently or temporarily. The losses in human lives, of materials, tools and machinery, interruption of communications, water and electric supplies were contributing factors.

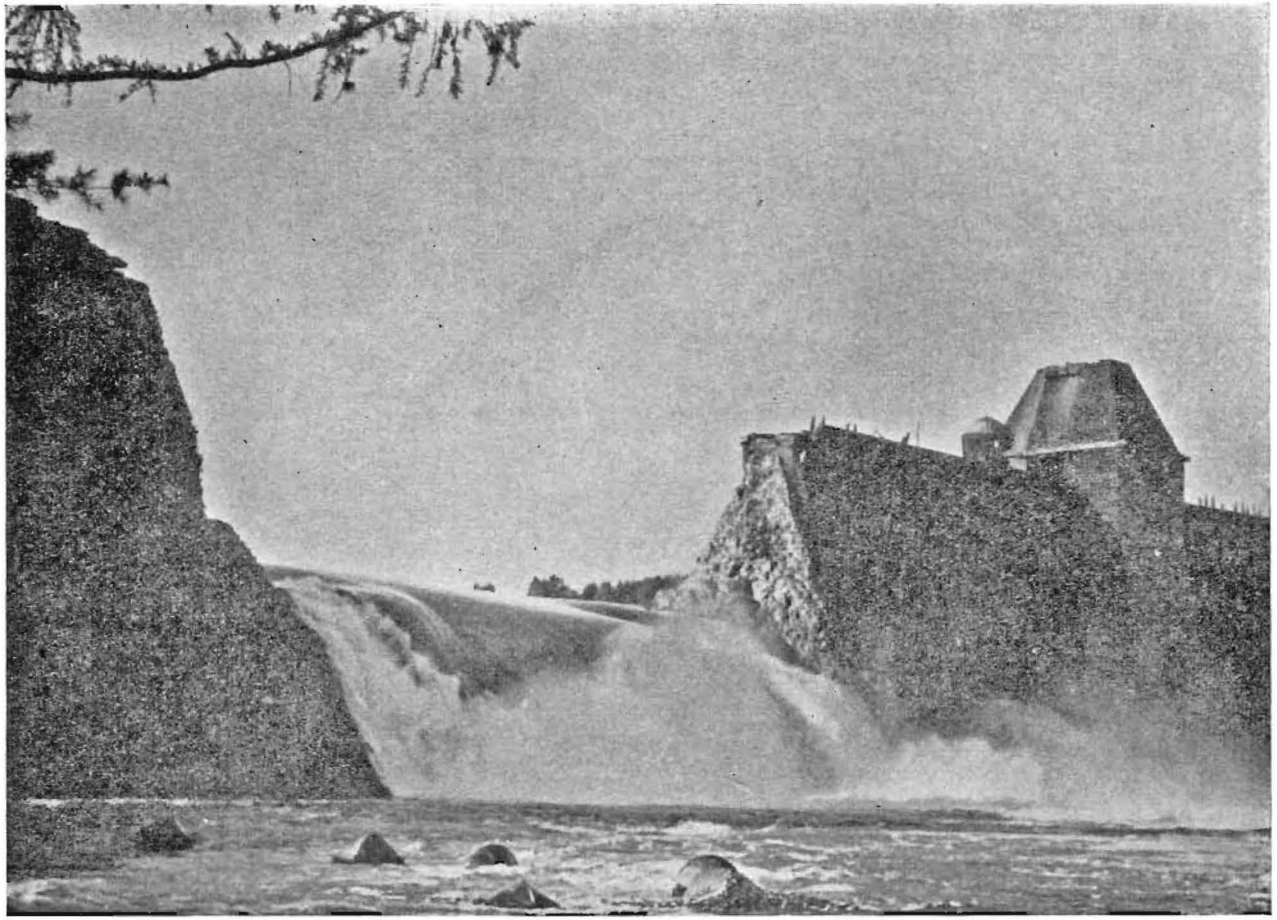
The effects of the attack were felt far into the Dusseldorf district.

The anticipated damage to the water supply system is of the most far-reaching importance. The Möhne dam is the backbone of this system, serving the whole right Rhine-Westphalia industrial area, which is inhabited by about 4½ million people. With the loss of the Möhne Dam, the available reservoir space has been halved. The result will be that the additional supply of water to the Ruhr will have to be curtailed. The quality of the water will be adversely affected and consumption, unless supplies can be got from other sources such as the Lippe, will have to be cut down, even for industrial consumers. It will depend largely on the speed with which repair work can be carried out and also on the weather during the autumn, to what extent industrial—in part war industrial—production will be affected.

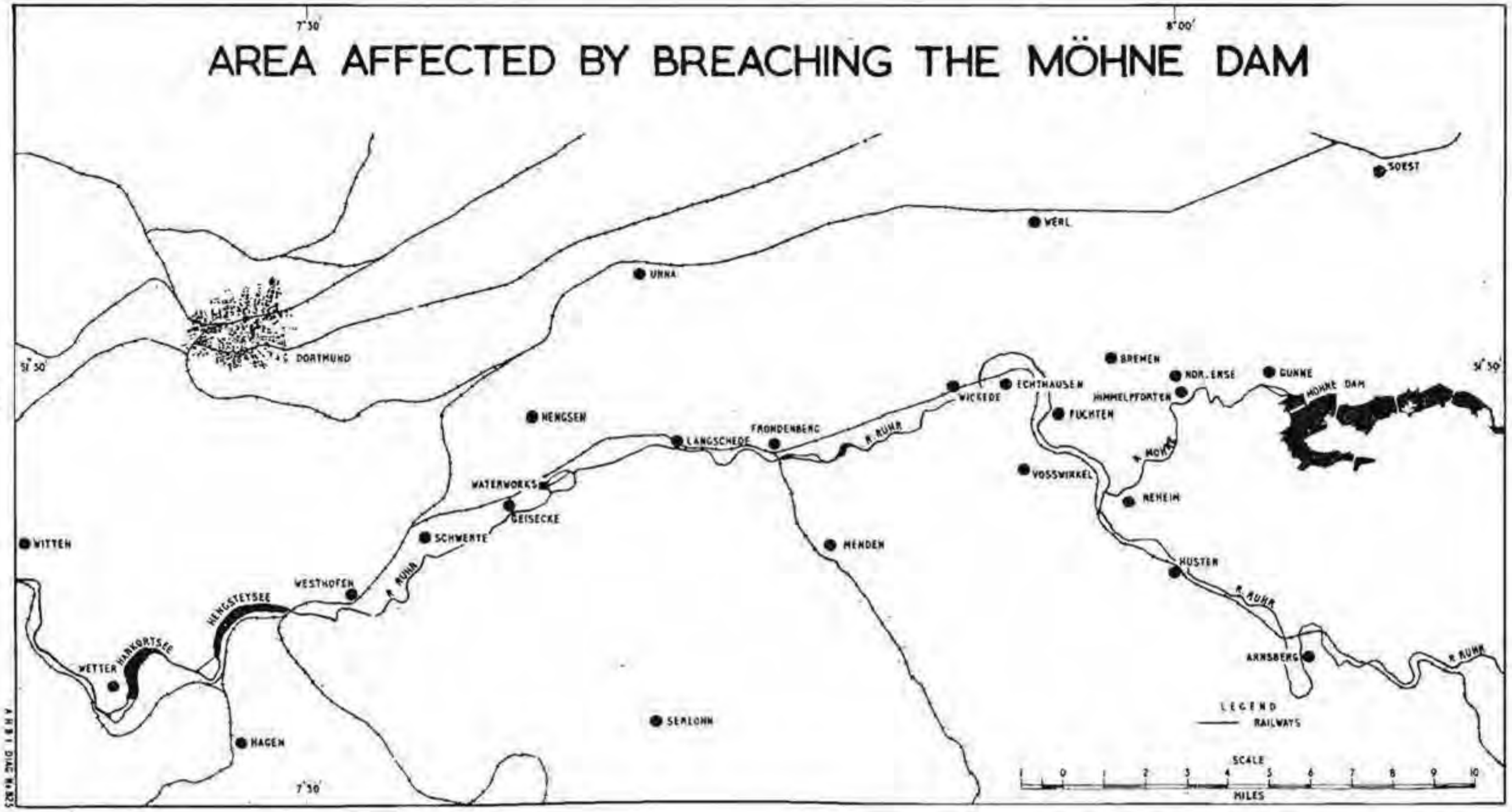
Influence on town and country planning : It would seem desirable, when restoring damaged and destroyed property, to pay due attention to improvement and planning. Actually the planning of the area hit by the disaster left much to be desired. A fact preventing large scale replanning is, that it is necessary to restore traffic and production as quickly as possible. The railway authorities who had planned to improve the line from Hagen to Kassel, have therefore been forced to abandon the scheme and merely restore the line to its previous condition. It will however be possible to introduce new plans in some cases where road and town planning can be carried out. It is, for example, planned to rebuild totally destroyed farm houses in different form and move them entirely out of the reach of flood waters, whilst the town area of Neheim in the valley of the Möhne can be completely replanned. In the latter case factories would, of course, have to be rebuilt in their old locations, since the wastage of remaining buildings and foundations could not be entertained at present. Two other factors would also have to be considered—whether, by moving the Möhne bed, a more favourable channel could be found, thus gaining valuable industrial land ; and whether a better route could be found for the Niederense-Soest road, if the upper bridge on the Möhne in the town area were rebuilt. At the same time the question of a revision of the route taken by the narrow-gauge railway Neheim-Niederense and its connections with the Neheim factories will have to be dealt with. In order to clarify the position, I intend to hold a conference of all the authorities concerned. I shall report the result of these talks in due course.



Möhne Dam



THE MÖHNE DAM AFTER ATTACK


AREA AFFECTED BY BREACHING THE MÖHNE DAM
7°30'
8°00'
51°30'
SOEST
WERL
UNNA
DORTMUND
BREMEN
NDR. ENSE
GUNNE
MÖHNE DAM
ECHTHAUSEN
HIMMELPFORTEN
WICKEDE
FUCHTEN
HENGSEN
LANGSCHEDE
FRONDENBERG
R. RUHR
R. MÖHNE
VOSSWINKEL
WATERWORKS
GEISECKE
NEHEIM
SCHWERTE
WITTEN
MENDEN
HUSTEN
WESTHOFEN
HENGSTEYSEE
HARKORTSEE
WETTER
ARNSBERG
LEGEND
RAILWAYS
SEMLOHN
HAGEN
SCALE
MILES

APPENDIX 12

BOMB PISTOLS IN USE IN THE R.A.F. IN 1919

Nose pistols

No. 8. .. A simple type of pistol used in 112 lb. and 520 lb. R.A.F. bombs.[1]

No. 9 .. Similar to but larger than No. 8. Used in 112 lb., 520 lb. and 550 lb. R.L. (Royal Laboratory, Woolwich) bombs.

No. 11 .. No recorded description exists except for its use in R.L. type bombs.

No. 13 .. A pistol produced for the S.N.[2] type bomb, the largest used in the 1914–1918 War. Weight 1,650 lb.

No. 14 .. A modified No. 9. The rotation of the arming vanes screwed the sharp pointed striker into the bomb during its flight. Used in R.L. old type bombs.

No. 15 .. A modified No. 8. Action identical to No. 14 but had parallel threads for use in old type R.A.F. bombs.

No. 16 .. A special type of nose pistol for use only with 20 lb. 'Cooper' bomb. In this pistol instead of the arming vanes falling off in flight as is normal, they operated instead a series of gear wheels and brought the striker in line with the detonator. The number of revolutions could be pre-set enabling release at low altitude. This geared safety device was necessary in order to avoid premature explosion should the bomb strike the fixed undercarriage on release.

Tail pistols

No. 5B .. The standard tail pistol used in the majority of bombs in the first world war period. A very simple pistol with parallel threads for 'R.A.F.' bombs and equipped with thread adaptor for the 'R.L.' series.

No. 12 .. A special tail pistol for S.N. bombs.

APPENDIX 13

BOMB PISTOLS DEVELOPED BUT NOT PRODUCED FOR SERVICE USE, 1939–1945

No. 36 .. A modified No. 27 pistol for air burst as an interim to the photo electric (P.E.), and acoustic pistols for bombing the bomber with G.P. bombs. Developed between September 1939 and June 1940. Approved for service July 1940 but not produced in quantity or issued to the Service. M.A.P. File SB. 56620.

No. 43 .. A considered alternative to the No. 38, developed between November 1941 and October 1942; it was cancelled because of the introduction of the No. 45. M.A.P. File R/A 2299.

No. 50 .. A radio ground proximity pistol developed from a fuze in November 1941 for use with 4,000 lb. H.C. bombs. After trials at A. & A.E.E. and by operational units—10 bombs fitted with this pistol were dropped—development was abandoned in March 1943 and the design sealed for record.[3] M.A.P. File SB. 30712, M.A.P. File SB. 33824.

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[1] A.P.T. 50678/18, Encl. 40B. The initials 'R.A.F.' or 'R.L.' were given to earlier types of bombs to denote that they had either parallel (R.A.F.) or tapered (R.L.) threads for the pistol.

[2] An 'initial' title for special types of bomb designed for operation against 'Krupps' armament works at Essen.

[3] No doubt because of R. P. Fuze development was handed over to American research at about this time.

No. 59 .. Designed by R.A.E. for tail pull percussion operation with parachute attached, 500 lb. H.C. bombs. Development and trials went on in conjunction with that of the parachute and special tail unit from April 1943 to September 1944. By this time the pistol although reliable was considered unsafe and work was in hand on an alternative (No. 61). M.A.P. File SB. 46752.

No. 61 . A No. 61 All-Ways Pistol modified to a R.A.E. design for the same purpose as the No. 59 but with improved safety. Quite successful in trials but hostilities ended before it was approved for Service use. M.A.P. File R/A 6837.

APPENDIX 14

SOME BOMBING RESULTS BY Nos. 9 AND 617 SQUADRONS—1945

Bielefeld Viaduct : 14 March 1945

Squadron .. No. 617.

Aircraft .. Lancaster (15).

Bombs .. .. 12,000 lb. in 14 aircraft.
22,000 lb. in 1 aircraft (this was the first 22,000 lb. bomb to be dropped on operations).

Release Height .. 11,000 to 12,000 feet.

Sight .. .. Stabilised Automatic Bombsight, Mark IIA.

Result .. .. 12,000 lb. bombs closely grouped round the massive concrete target, which carried four railway tracks across a stretch of low-lying marsh land.

22,000 lb. bomb fell within a few feet of the north side of the viaduct.

The below-ground detonation completely upset the foundation of the viaduct : six of the concrete spans collapsed.

Vlotho : 19 March 1945

Squadron .. No. 9.

Aircraft .. Lancaster (18).

Bombs .. .. 12,000 lb.

Release Height .. 12,000 to 14,000 feet.

Result .. .. Complete collapse of one of the central supporting piers of the viaduct, which fell into the river.

Amsberg : 19 March 1945

Squadron .. No. 617.

Aircraft .. Lancaster (20).

Bombs .. .. 12,000 lb.

Release Heights .. 11,000 to 14,000 feet.

Result .. .. Six direct hits : 40 yard gap torn in the viaduct.

Arbergen : 21 March 1945

Squadron .. No. 617 (Lancaster) (S.A.B.S.).

Bombs .. .. 12,000 lb.

Release Heights 13,000 to 14,000 feet.

Result .. .. Two sections of the approach viaduct destroyed, and the bridge made useless.

Nienburg : 22 March 1945

Squadron ..	No. 617 (Lancaster) (S.A.B.S.).
Release Heights	9,000 to 10,000 feet.
Result	Very accurate bombing : bridge almost totally destroyed, approach viaducts severely damaged.

Bremen : 22 March 1945

Squadron ..	No. 9 with 65 supporting aircraft from other squadrons (Mark XIV).
Release Heights	17,500 to 19,500 feet.
Result	Heavy concentration round the bridge which, however, escaped severe damage.

Bremen : 23 March 1945

Squadron ..	No. 617 with supporting aircraft (S.A.B.S.).
Release Height ..	24,000 feet.
Result	Bridge wrecked in spite of enemy smoke screen : extensive damage to tracks on each side.

Bad. Oeynhausen : 23 March 1945

Squadron ..	No. 9 (11 Lancasters) : Mark XIV Sight : Bombs, 12,000 lb.
Release Heights	13,000 to 14,000 feet.
Result	Two direct hits : central span of Northern track fell into the river.

This raid was the last of the series : seven bridges or viaducts had been put out of action in 10 days : brilliant bombing is not an exaggerated description.

The Tirpitz : 12 November 1944

After many unsuccessful attacks, including those of dive bombers of the F.A.A., *Tirpitz* was finally attacked by aircraft of No. 9 and 617 Squadrons, while mooring in Alten Fiord.

All aircraft carried 12,000 lb. bombs. Three direct hits and many near misses were obtained and the ship sank within 9 minutes of the release of the first bomb.

Release Heights : 13,000 to 16,500 feet.

High level precision bombing at night

Gnome-Le-Rhone and engine factory, Limoges, 8 February 1944. *Squadron No.* 617 (S.A.B.S.).

This was an outstanding example of a precision night attack. Twelve Lancasters attacked the target which had been marked by incendiaries dropped at roof height by the Squadron Commander. Six aircraft carried 12,000 lb. bombs and six sticks of twelve 1,000 lb. bombs.

Twenty-one bays of the machine shop out of a total of 48 were destroyed, and the remaining three were severely damaged ; 17 bays suffered roof displacement and a building of the boiler house and transformer station was destroyed. Only two bombs fell outside the target area.

Release Heights : 7,000 to 10,400 feet.

This attack was the fore-runner of many similar successful attacks by No. 617 Squadron.

Saumur tunnel : 8 June 1944 (Night of 'D-day plus 2')

This attack was made on a vital route leading to the Normandy bridgeheads. Lancasters of No. 617 Squadron were forced by cloud to bomb at under 9,000 feet, a difficult height. 12,000 lb. bombs were used and the mouth of the tunnel was blocked.

Release Heights : 3,000 to 10,500 feet.

APPENDIX 15

BOMBSIGHTS AND THEIR DESIGNERS, 1916–1945

Type of Sight.	*Principal Designer.*	*Date.*	*Development or Production Firm.*
Course setting bombsights :			
Mark I ..	Mr. H. C. Wimperis (Air Ministry Laboratory).	1916	Messrs. Elliotts.
Marks II–III ..	Staff of A.M. Laboratory	1918–1932	Messrs. E. R. Watts.
Mark IX ..	W. H. Coulthard ..	1935	Messrs. R. B. Pullin.
Mark IXA & B	P. B. N. Nuttall-Smith	1938	Messrs. Dekko Cameras.
Azimuth bracket	R. S. Capon .. .. G. D. Davis.	1938	Messrs. S. Smith.
Mark X ..	T. W. Barnes	1939	Messrs. Creed.
Other Vector sights			
Mark XI ..	L. G. Carpenter ..	1940	Messrs. Avons Electricity Meters.
Mark XII ..	Prof. R. M. S. Blackett	1941	Messrs. Powers Accounting Co. Messrs. Avons.
Mark XIV ..	Dr. H. J. J. Braddeck ..	1941	Messrs. Powers Accounting Co. Messrs. Avons.
Mark XV ..	W. H. Coulthard ..	1942	R.A.E. prototype only.
Mark XIII ..	J. C. Ballantyne ..	1945	Messrs. Avons.
Tachometric bombsights			
Automatic bombsight			
Mark I ..	L. C. Bygrave .. .. W. J. Richards.	1936	Messrs. Creeds. Messrs. Halls Telephones.
Mark II ..	W. J. Richards .. .. S. E. Kirk (of Messrs. Creeds).	1938	Messrs. Creeds.
Stabilised automatic bombsight			
Mark I ..	J. W. Barnes	1940	Messrs. Creeds.
Mark II .. } Mark IIA .. }	J. W. Barnes	1941–1944	Messrs. Desoutters. Messrs. Powers Accounting. Messrs. Smith Instruments. Messrs. Electroflo. Messrs. British Thermostats.
Low altitude sights			
Low level bombsight			
Mark I ..	F. E. Lamplough .. W. H. Coulthard.	1940	Messrs. Enisen.
Mark II .. (Observer's sight)	Prof. R. M. S. Blackett	1943	Messrs. Avons.
Mark III ..	D. A. Richards	1943	Messrs. Avimos.

Type of Sight.	*Principal Designer.*	*Date.*	*Development or Production Firm.*
Miscellaneous sights			
Simple level bombsight.	J. W. Barnes ..	.. 1938	R.A.E. prototype.
Pursuit bomb-sight.	W. T. Richards ..	.. 1939	R.A.E. prototype.
Scatter bomb-sight.	W. H. Coulthard	.. 1939	Messrs. Pullins.
Type G.1 .. / Type G.2 ..	W. H. Coulthard / W. H. Stenn.	.. 1941	Messrs. Pullins.
Dive bombsight	F. W. Meredith ..	.. 1941	Messrs. Smiths Instruments.

APPENDIX 16

SCHEDULE OF REQUIREMENTS FOR EMBODIMENT IN DESIGN OF NEW UNIVERSAL BOMB CARRIERS

Bomb carriers are required for carrying and releasing bombs of various weights and sizes, and in order to avoid a multiplicity of carriers—each one suitable for one particular type of bomb—it is desired to obtain designs of two universal types of carrier, the one to readily carry any bomb between 50 lb. and 300 lb. in weight, and the other to easily accommodate any bomb between 200 lb. and 600 lb. in weight.

The new bombs will all be of similar contour but will differ in weight, length and diameter. The bombs will be provided with both nose and tail fuzes and the carriers must have the following essential features :—

1. The bombs must be housed on the carriers so that their major axes be in the horizontal plane and parallel to the fore and aft line of the aircraft.
2. The bombs, when loaded, must have their tail drums at the rear of the carriers.
3. Ease of loading must be assured.
4. Carriers must be so designed that they show a sufficient factor of safety, with bomb load, when the aircraft on which they are loaded is either :—
   (*a*) Taxying over rough ground.
   (*b*) Banking steeply in flight.
   (*c*) Side slipping.
   (*d*) Involved in a minor crash.
5. The carriers must have a factor of safety of not less than four.
6. The carriers must be as light as possible, consistent with strength.
7. The release slip (which is a standard unit) must be in a fixed position on the main framework for all bombs.
8. The carrier must provide for optional fuzing of all bombs, *i.e.* it must be possible either to render the tail fuze operable only, or allow both nose and tail fuzes to function, or to allow the bomb to be released with both fuzes inoperable.
9. The carriers must be provided with attachments to allow of easy fitting to standard bomb ribs which are spaced at 21-inch centres, without having to resort to complicated methods of bracing to the aircraft structure.
10. All adjustments must be effected by means of ordinary tools.

APPENDIX 17

AIR STAFF REQUIREMENTS FOR A STANDARD BOMB CARRIER FOR USE WITH INTERNALLY STOWED BOMBS OF 250 LB. TO 500 LB. CARRIED IN SINGLE TIER STOWAGE

Introduction

With the advent of internal stowage for bombs and the vastly increased carrying capacity of modern aircraft, it is necessary to reconsider our method of handling and carrying bombs.

The following points, which have a bearing on the type of carriers required, have been decided:—

(i) Each aircraft of the near future types will be provided with duplicate sets of carriers. In the more distant future it is hoped to evolve a type of carrier which will obviate the necessity of providing duplicate carriers.

(ii) The carriers will be fitted to the bomb at the fuzing point whilst the bomb is resting in crutches on a trailer.

(iii) The bomb and carrier will be transported by trailer to a point where the aircraft will come to pick up its load. The bombs will be laid out on wooden crutches on the ground and the aircraft moved over them. Alternatively the bomb trailers carrying the bombs may be manœuvred under the aircraft and hoisted from the trailers into the aircraft.

(iv) Simplicity and speed of operation are all important and the minimum of work, namely, hoisting into position only, is to be done in the bomb cell under the aircraft.

I. Types of bombs to be accommodated

The following types of bomb must be accommodated without any alteration to the carrier other than adjustment of crutches and fuzing boxes: 250 lb. G.P., 250 lb. S.A.P., 250 lb. A.S., 250 lb. 'B,' 250 lb. L.C., 250 lb. S.C.I., 250 lb. S.B.C., supply dropping apparatus Mark VB; 500 lb. G.P., 500 lb. S.A.P., 500 lb. A.S., 600 lb. S.C.I.

II. Types of release slip and fuzing gear

The standard single hook type release slip and E.M. release and fuzing units must be employed.

III. General features

The carriers must be simple to produce; light; occupy a minimum vertical space; compact; and sufficiently robust to withstand catapult loads and ground handling. Consideration must also be given to the suitability of the carrier for stowing the duplicates in the aircraft when engaged in reinforcing operations. It must be easy to maintain, and provided with adjusting devices which can be operated in the minimum of time with the minimum of tools.

IV. Special features

Quick operation throughout the various phases of the bombing-up operation is essential, special attention should be paid therefore to the following points:—

(i) Accessibility of all adjustable parts, and accessibility for checking engagement of release slip, E.M., release unit and fuzing gear.

(ii) The provision of snap-up connections for the attachment of the carrier to the aircraft, and similar snap-up electrical connections between the carrier and aircraft. All these connections should be provided with adequate 'leads' to guide the fittings to their final locations.

(iii) A small winch is required over each bomb carrier position. These winches should be operated preferably from the outside of the bomb cells and so geared that one man can hoist a 500 lb. bomb rapidly and without fatigue. A ratchet must be provided to prevent accidental lowering of the carrier and bomb, and means must be provided for manual disengagement of the ratchet if desired.

(iv) The bomb crutches must be easy and rapid to adjust and free from lock nuts, adjustment by means of an irreversible worm and wheel is the type of mechanism envisaged.

APPENDIX 18

TYPES OF BOMB TROLLEY

Type 'A'	Designed to carry a maximum load of 500 lb. Now obsolete.
Type 'B'	Designed to carry 4 × 250 lb. or 2 × 500 lb. bombs. Spring suspension. Stores carried on crutches. Centre beam has a maximum clearance of 4 inches, and is adjustable to give a maximum clearance of 16 inches. Obsolescent.
Type 'C' Mark I ..	Designed to carry 1 × 2,000 lb., 2 × 1,000 lb., 4 × 500 lb., or 8 × 250 lb. bombs. Spring suspension. Stores carried in saddles. Side members have a clearance of 12 inches.
Type 'C' Mark II (Modified Mark I)	Designed to carry 8 × 250 lb., 6 × 500 lb., 3 × 1,000 lb., 1 × 1,900 lb., 1 × 2,000 lb., or 2 × 1,500 lb. 'A' mines. No springs. Flat top. Side members have a clearance of 8¼ inches.
Type 'C' Mark III	Details as for Mark II, but will also carry 1 × 4,000 lb. bomb. (Suffolk Iron Foundry Production.)
Type 'C' Mark IV	Details as for Mark II, but has not been cleared for carriage of 1 × 4,000 lb. bomb. (Alvis Motor Co. production.)
Type 'D' Mark I ..	Designed to carry a range of stores up to a maximum load of 4,000 lb. and including 1 × 4,000 lb. bomb. Spring suspension. Stores carried in saddles. Clearance of side members is 6⅜ inches in low position and 11⅜ inches in high position.
Type 'D' Mark II	Designed to carry 1 × 4,000 lb. bomb. No springs. Flat top. Clearance of side members is 6⅜ inches.
Type 'D' Mark III	Designed to carry 1 × 4,000 lb. bomb. Rear sprung (Cantilever spring). Flat top. Clearance of side members is 6⅜ inches in low position, and 11⅜ inches in high position.
Type 'E' Mark I ..	Designed to carry 1 × 4,000 lb., 2 × 4,000 lb., 1 × 8,000 lb. or 1 × 12,000 lb. bomb. Wheels independently sprung. Flat top. Clearance of side members is 7½ inches unladen and 6½ inches fully laden.
Type 'F'	Designed to carry a range of stores up to and including 1 × 8,000 lb. bomb. Flat top. No springs. Clearance of side members is 5½ inches.