

THE THIRTY-FOURTH THOMAS HAWKSLEY LECTURE

The Rocket as a Weapon of War in the British Forces

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INTRODUCTION

In the World War of 1939–45, an outstanding feature of armament development was the extensive use of rocket weapons by the major belligerents.

These rockets represented not so much the evolution of a new type of weapon as the modernization of one of the oldest of weapons. The exact date of the discovery of the rocket principle is a matter for speculation, but there is no doubt that rockets were used in warfare many years before the development of the early forms of cannon. Their use continued, with occasional breaks, until the end of the nineteenth century, when they fell into the background. The improved performance and accuracy of guns, resulting from the introduction of recoil mechanisms, steel rifled gun barrels, and the use of colloidal propellants, established new standards with which the rocket could not compete at the time.

During the World War of 1914–18 there was a brief return of military interest in rockets, notably in the United States, where R. H. Goddard of the Smithsonian Institute, with the assistance of C. N. Hickman, undertook the development of artillery rockets for the U.S. Army, but the project was abandoned when the war ended. Later these investigators carried out experiments with small rockets propelled by liquid oxygen and petrol; and they forestalled in principle much of the technique embodied in the German "V2" rocket used in the war of 1939–45.

The significant revival of interest in the subject took place some fifteen to twenty years ago, particularly in Germany. Here, the emphasis was at first on industrial applications, and a number of rocket societies were formed to further rocket development in this field. Later, the German military authorities became interested, and they embarked on an active and comprehensive programme of research and development.

With the advent of the Nazi regime, these activities were intensified. A new establishment was set up at Peenemünde on the Baltic coast at a capital cost reputed to be in the neighbourhood of 300,000,000 marks; and other Government establishments were founded to explore the several technical problems allied with the various aspects of the general field of rocket development.

Research and development continued progressively in Germany, and the effort grew to such proportions that it was estimated that during the latter part of the 1939–45 war it took up the full time of some two thousand five hundred scientists and technicians.

In this lecture I propose to confine myself to a survey of the work carried out in the United Kingdom on the development of rockets for military purposes, as far as is possible within the time at my disposal. In view of the wide field to be covered, and for other reasons which I am sure you will appreciate, I shall present the subject mainly from the descriptive angle.

INCEPTION OF ROCKET DEVELOPMENT IN ENGLAND

The reports that were received by our Government in 1934 about German activities led to the serious consideration by the

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War Office of the desirability of developing high-velocity rockets in this country. The first meeting to discuss the subject was called in December 1934; and in April 1935 the Research Department at Woolwich Arsenal was asked to put forward a programme for the specific investigation of the possibility of developing rockets, utilizing cordite as the propelling agency. Preliminary work was started in the Research Department in May 1935, and by the summer of 1936 encouraging advances in technique had been achieved. In July of that year it was decided to undertake the systematic study of rockets for various warlike purposes, and the development was co-ordinated under the direct guidance of a subcommittee of the Committee of Imperial Defence, namely, the Subcommittee on Air Defence Research. I was entrusted with the task of controlling the new field of development.

The original main lines of objective that were laid down for intensive study were in order of priority:—

- (a) Anti-aircraft defence.
- (b) Long-range attack.
- (c) Air weapon against hostile aircraft.
- (d) Assisted take-off for heavy aircraft.

Of these, (a), (b), and (c) were judged to be of considerably greater importance than (d). It may be noted that as far back as eleven years ago there was a direct interest expressed in the long-range offensive use of the rocket; and we had under active consideration designs for two types of long-range rocket, one with a range of 500 miles and the other with a range of 900 miles. It may or may not have been accidental that these two ranges corresponded very closely with the distances from London to Berlin and London to Rome respectively.

However, the work that had been started on these long-range applications soon had to yield to other more urgent needs, in view of the increasing pressure on armament development occasioned by the threat of war; and the item was fairly early taken out of the programme so that the effort that was available could be concentrated on a purely defensive type of weapon. In fact, for the two years immediately preceding the war, all that could be done with the facilities at our disposal was to concentrate on the anti-aircraft problem; and this was explored from the point of view of obtaining types of rockets which, though not ideal, would serve as war weapons and would relieve pressure on the manufacturing capacity of the country for orthodox guns. We had not, however, forgotten the need for the other types of weapons laid down by the Committee of Imperial Defence, and I shall be able to give you later on in this lecture some description of what we achieved in this direction.

EARLY ROCKET DESIGNS

Our first problem was to produce a rocket which would parallel the performance of the 3-inch anti-aircraft gun, and calculations showed that this could probably be done by the employment of a rocket of 2-inch calibre, using a solid propellant of the cordite type.

In the anti-aircraft application the prime requirement is that the time of flight shall be as short as possible; and to achieve this there must be a short time of burning of the rocket charge coupled with a high velocity at the end of combustion. The problem is to reduce to a minimum the weight of the metal

components, namely, the rocket tube, the nozzle, and the combustion chamber, and to secure at the same time the maximum gas velocity. To obtain a high rocket velocity, the ratio of the weight of the propellant to the overall weight of the rocket must be high, and the designer therefore must provide for as great a weight of propellant charge as possible consistent with the strength of the surrounding metal tube. The decision to use a solid charge in place of a liquid fuel system was taken in order to avoid complexity of design; it was in any case desirable from economic considerations.

The arrangement of the propellant charge in this first experimental type of rocket is indicated in Fig. 1, and exhibits a

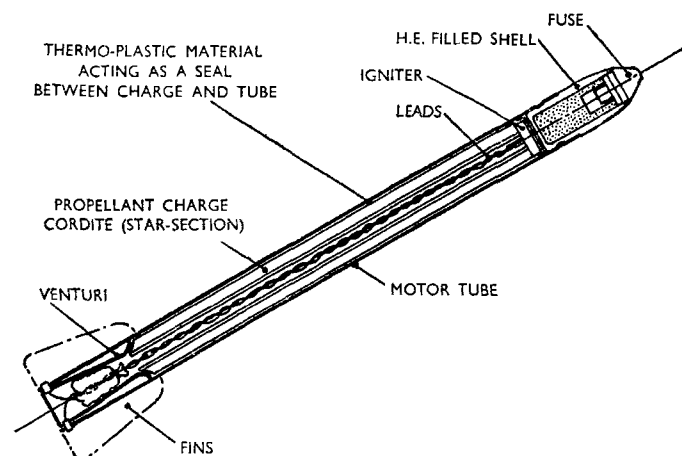


Fig. 1. Experimental 2-inch Rocket Motor (Charge secured by Plastic Surround)

feature which may well form the subject of investigation in the future; although of necessity it was temporarily discarded in the rockets that were successfully developed in the war. Our early feeling was that it was improbable that the thin steel tube forming the casing of the rocket motor would be able to stand up to the duration of the period of burning of the charge, if the propellant gases, which have a temperature of about 2,500 deg. C. (about 4,500 deg. F.), were brought into direct contact with the metal surface. We investigated, therefore, the possibility of arranging for the propellant tube to burn on its inside surface only, and this involved solving the problem of inhibiting burning on the outside surface without seriously reducing the density of loading. Development was, therefore, put in hand of a suitable material having plastic properties to fill the narrow annulus between the propellant and the motor body; the intention being that the plastic should adhere strongly enough to the surfaces, both of the propellant and of the motor body, to exclude propellant gases, and at the same time be capable of flowing under the stresses due to temperature changes, whilst retaining its shape and position under the stress due to the weight of the filling. By making the internal contour of the charge a star-shaped cross-section it is possible to obtain an almost constant burning surface, so that the thrust remains relatively constant, and it is also possible to adjust the time of burning within limits.

After preliminary static firing experiments it became clear that it would be difficult to meet a specific requirement for the

rocket to have the same time of flight to 15,000 feet as the 3-inch anti-aircraft shell. This entailed an exceedingly high ratio of propellant weight to total rocket weight, and the situation was complicated because special materials and facilities for the production were already becoming restricted, so that there was nothing like a free choice open to the designer. However, some thin tubing was obtained in sizes which would fit the propellant near enough, and the first designs were based on these. The high ratio of length to diameter ruled out the possibility of spin stabilization, and fins had to be used.

It was soon found that the original thin steel tubing was unsatisfactory on account of ovality and eccentricity as well as the difficulty of strengthening so springy a material; and a change was accordingly made to electrically welded tube formed from 3 per cent carbon steel strip. The normal method of manufacture of high-grade steel tubing drawn from the solid invariably leads to a certain degree of eccentricity, and the rejection rate for such tubing to meet the stringent specification laid down for rockets was found to be prohibitive. A process was evolved and a plant was installed enabling steel strip to be rolled to a uniform closely controlled thickness, formed into tube, and electrically welded. The weld seam was then scarfed away and the tube cold-drawn for final dimensions.

This method had design difficulties. To ensure the soundness of the weld, on which its whole potentialities depended, the steel had to be of relatively low carbon content, with the resultant restriction of tensile strength. The tubes were, therefore, necessarily thicker and heavier than was desirable, with a resultant loss of performance. Moreover, the plant, once constructed, was relatively inflexible as regards the size of tube which could be produced, the limits lying between about 2 inches and 3½ inches in diameter. This was a condition that hampered us always; in fact the congestion in the tube industry as the war progressed was such that it was never possible to contemplate the manufacture of welded rocket tubes outside this range.

Early experiments during the spring and summer of 1937 were encouraging, and good and reliable performance was obtained in firing trials; but with the onset of colder weather in the winter of 1937 it became apparent that the development of a satisfactory material for the plastic surround had by no means been achieved. The material could not cover the temperature range involved. At temperatures over 80 deg. it became fluid, while at the low end of the range it again lost its plasticity and became tacky. Another difficulty was the effect of the exudation of nitro-glycerine from the propellant charge which seeped into the plastic surround and altered the plastic properties during storage. This was a very serious setback, and led to the decision to abandon the use of a plastically secured charge and go to a loose charge with free burning of all surfaces, at the same time utilizing a heat-insulating coat to protect the metal of the tube as far as possible from the hot gases. The first trials of this new arrangement were carried out in February 1938, using a plain cylindrical tube of propellant supported on a fabricated steel cross which acted as a trap to prevent the tube setting back into the nozzle throat. Given sufficient clearance between the propellant and the steel tube, this arrangement proved very successful, and it was found that malleable cast iron grids could be made to withstand the most severe conditions.

A typical loose charge rocket motor is illustrated in Fig. 2. The propellant charge itself is a plain cylinder of cordite; and, after ignition, burning takes place on all exposed surfaces. The

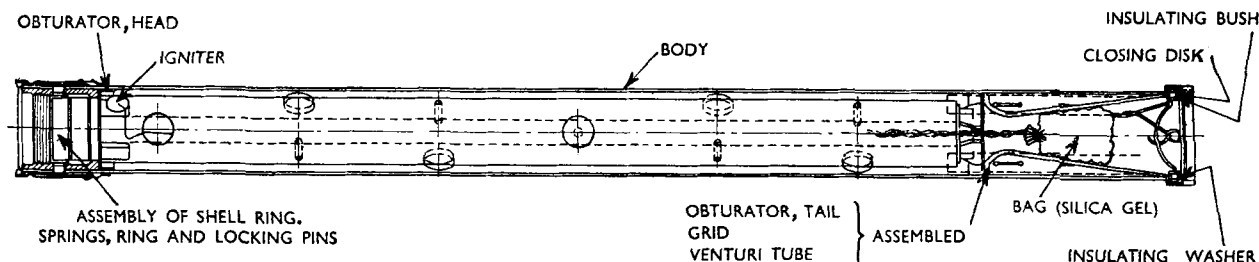


Fig. 2. 2-inch Rocket Motor (Loose Charge)

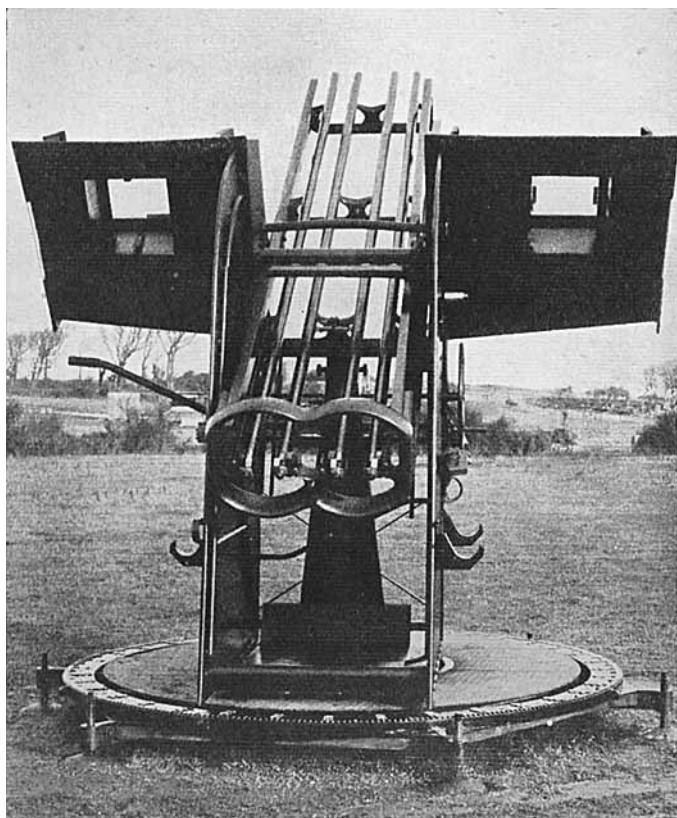


Fig. 3. 3-inch Rocket Twin Anti-aircraft Projector

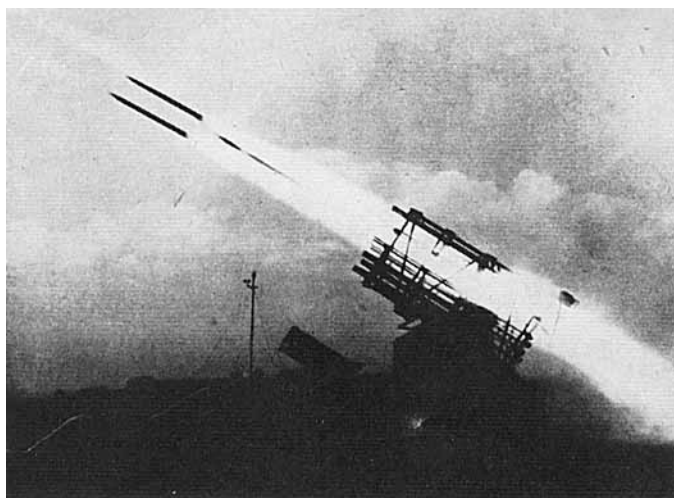


Fig. 4. 3-inch Rocket Nine-barrel Anti-aircraft Projector

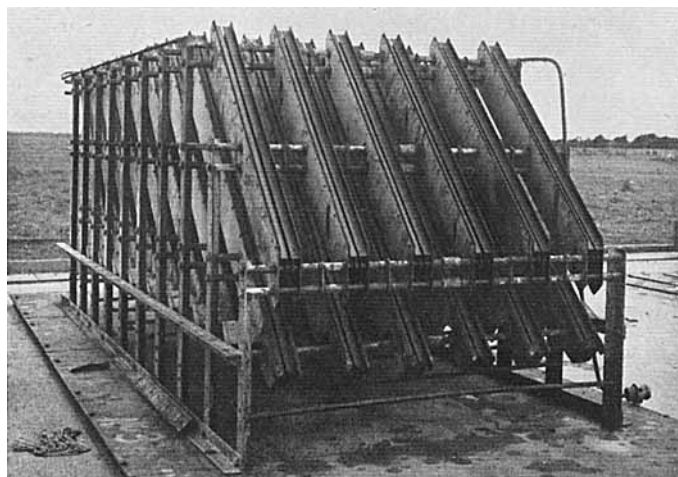


Fig. 7. Naval 5-inch Multiple Projectors ("Mattress")

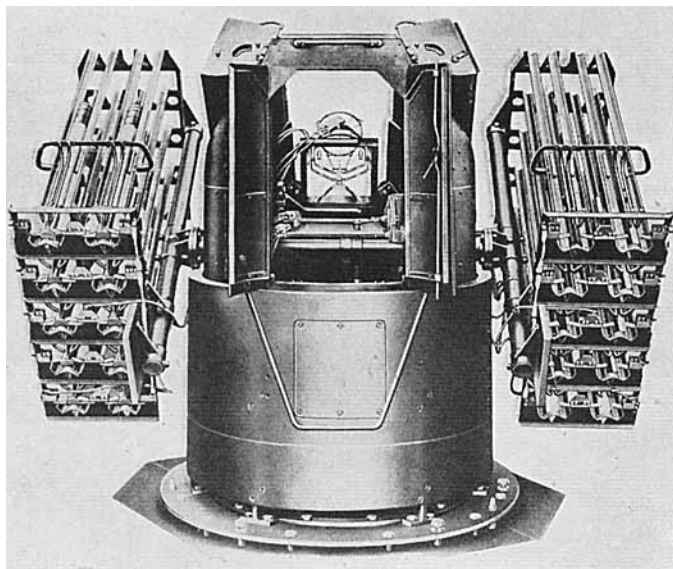


Fig. 6. Naval 2-inch Multiple Projector ("Pillar-box")



Fig. 8. Salvo from "Mattress"

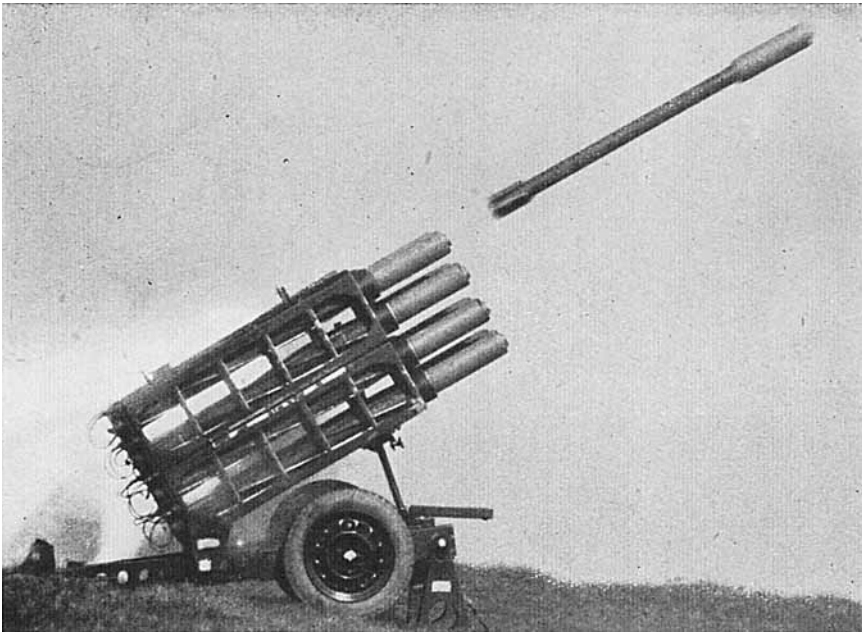


Fig. 9. Land Mattress in Action



Fig. 10. Land Mattress being Loaded



Fig. 11. Airborne Rockets being Loaded



Fig. 12. A Beaufighter Firing a Pair of 60 lb. (High-explosive Head) Rockets

charge, although loose, is a fairly good fit between the obturator at the head end and the grid with obturator at the tail end. It is centred in the surrounding metal tube by tabs of inert and relatively incombustible material, which are arranged in a spiral around the charge and stuck firmly to the cordite.

Ignition is electric; wires being carried from metal contacts in the rear end of the motor through the centre of the charge to the igniter at the head end of the motor assembly. This ensures, as far as possible, that the gas flow is unidirectional from the head end to the nozzle.

A closing disk is provided at the rear end, which vents when the pressure developed by the gases has reached a critical figure; this is necessary to ensure regularity of action and burning. In the divergent part of the nozzle is placed a bag containing a drying agent such as silica gel to ensure good keeping qualities on storage.

The motor is closed at the head end by a shell ring secured into the rocket body by spring pins. Into this ring is screwed the projectile proper, containing the explosive charge or other filling.

The problem of the coating for insulating the walls of the rocket motor from the effects of the hot gases was overcome, after a prolonged series of experiments, by spraying the inside of the motor tube with a suspension of finely ground alumina in a solution of sodium silicate. The physical condition of the alumina, the method and fineness of grinding, the chemical composition and physical properties of the silicate, the duration, atmosphere, the temperature for preheating and final baking were all found to be critical. However, by rigid control of the supply of materials, and by insistence on carefully prescribed conditions of operation, the process was industrialized, and the refractory coating was successfully applied to several millions of rockets. Although the thickness of the coating was only 0.008 inch, the reduction in wall temperature at the end of burning was found to be of the order of 300 deg. C. (572 deg. F.), which resulted not only in preventing the tubes burning out, but also in the achievement of a real improvement in accuracy of flight.

These two major changes—from the thin alloy steel tube to the thicker material, and the adoption of the loose charge with its reduced outside diameter and consequent reduced weight—brought the performance of the weapon below that originally specified; but our first war rocket had been born. In the course of time there were many improvements in design, and many modifications were made to the components and to the assembly of the components; but the early 2-inch rocket was destined to be the prototype of a number of important weapons in the general armament programme, particularly for naval purposes.

THE 3-INCH ANTI-AIRCRAFT ROCKET

About a year after the start of the development of the 2-inch rocket a demand was received for a larger and more powerful weapon to have a performance approximating to that of the new 3.7-inch anti-aircraft gun, which was just on the point of coming into the service. This led to the investigation of a 3-inch calibre rocket, and while this was in no way a straight "scaling up" from the 2-inch rocket design then under investigation, the general features of the two types were very similar. As in the case of the 2-inch rocket, the early experiments with the 3-inch model were made on the basis of securing the cordite charge with a plastic surround; and exactly the same difficulties were encountered at the low end and at the high end of the temperature range of use.

The decision was therefore taken to adopt the loose type of charge in the 3-inch rocket also, and to accept the reduction in performance thus entailed. This decision was criticized at the time on what then seemed to be good grounds. Nevertheless, in the long run, it proved to have been a wise move; otherwise, when the need for the use of the weapon became acute, as it did soon after the start of the war, there would have been no rockets of this type available and capable of quantity production.

A design that was regarded as generally satisfactory for extended trial was evolved by the end of the summer of 1938; and fuse-scale and trajectory trials were planned to take place the following spring and summer. The Munich crisis precipitated action, and it appeared inadvisable to delay the trials. Conse-

quently, as winter weather conditions in England are unsuitable for work of this kind, a search was made for a suitable site in a more favourable climate. Such a site was found in Jamaica, and some 2,500 rounds were fired there during the winter of 1938-9 in an extensive series of ballistic trials.

The results were unacceptable to the General Staff; since the performance fell short of that specified, and the accuracy of shooting compared unfavourably with the new 3.7-inch anti-aircraft gun. Nevertheless, the development work was continued up to the outbreak of war in the hope that the accuracy could be improved; but when the war started the priority accorded to the work was drastically reduced to enable the effort available to be concentrated on more immediately urgent projects.

Some three or four months after the outbreak of war, the concentration shown by the Germans on the use of dive-bombing tactics led to a revival of interest in the 3-inch rocket coupled with the use of a proximity fuse. One of the major preoccupations in the field of armament development during the very early stages of the war had been the consideration of the possibility of developing a fuse which would trigger itself automatically when the projectile to which it was fitted passed within lethal range of an aircraft. Various devices of this nature were under investigation, and of these the one which had reached the most advanced stage of development was a photo-electric fuse. In principle this device included a photo-electric cell which was coupled to a thermionic amplifier; and the circuit design was arranged so that when the image of an aeroplane target was projected on to the cell by a lens, there would be a sufficiently large change in emission from the cell to generate a pulse capable, when amplified, of setting off a gas relay in circuit with the detonating train to the shell. Safety switches were included in the circuit to ensure that the fuse would be inert until after the rocket was launched.

Firing at a target approaching along the line of sight, which is the condition for countering a dive-bomber, gives a very high expectation of causing lethal damage with a fuse of this type. The projector for launching the rocket can be extremely simple in design, and the only correction necessary in laying is for wind deviation. The delicate construction of the fuse, together with its bulk, precluded at the time its use with conventional artillery, but the 3-inch rocket was an ideal vehicle.

The project was sponsored jointly by the Admiralty and by the War Office, and development proceeded apace.

By the summer of 1940 most of the technical difficulties in the design of the fuse had been overcome, and preliminary production was under way. A projector for landing the rocket was evolved which was so cheap and simple in construction that it could be produced in large quantities without elaborate manufacturing facilities, and could be used by personnel with relatively little military training. Several thousands of these projectors were made during 1940-1 for use in the defence of vital targets such as key factories and rail heads.

In November 1940 a twin projector was designed on the general lines of the single projector, but incorporating a number of improvements which experience with the earlier design had shown to be desirable. This projector is illustrated in Fig. 3, Plate 1.

Meanwhile the photo-electric fuse was coming off the production lines in fair quantities; and trials were being carried out for clearance, including firings at glider targets suspended from captive balloons. A number of factors, however, combined to prevent the fuse coming into operational use, other than on a few exceptional occasions. In the first place the expected menace of the dive bomber had not materialized to anything like the extent that had been feared, and in the second place the limitations of the fuse principle prevented the extension of its use against aircraft in other roles. The most serious of these limitations were the inability of the fuse to function at night or at dawn or at dusk, and its tendency to give prematures when fired in certain directions relative to the position of the sun. The decision was therefore taken to suspend production of the fuse, and replace it by a time fuse of more conventional type.

By the end of 1940 the German campaign of bombing England by night had reached such intensity that the available anti-aircraft gunnery resources were being strained to the limit. The

3-inch anti-aircraft rocket therefore came into demand for the role for which it had originally been intended, namely, supplementing the heavy gun defences. The possibility of this was foreseen during the summer of 1940, and by arrangement between the War Office and the Ministry of Supply an experimental regiment was formed in October 1940 to study the new operational technique and to produce a drill for using rockets against high-flying heavy bombers. This regiment worked in the closest association with the rocket development establishment in Wales; and the collaboration resulted in the production of a complete drill and training scheme, together with many practical improvements in the equipment as a whole and in the system of fire control. Later, in March 1941, the regiment was given an operational role under A.D.G.B. in the defence of the Cardiff area. On 7th April 1941 it destroyed its first aircraft.

In addition to the single and twin projectors, a number of multiple barrel equipments on mobile mountings were produced by conversion of 3-inch anti-aircraft gun mountings.

Batteries formed of these multiple equipments were used in the Mediterranean during the North African campaign in the defence of ports, in addition to employment in the United Kingdom. A typical projector is illustrated in Fig. 4, Plate 1.

The rockets were fired in salvos, up to 128 rounds at a time in the case of batteries of twin-barrelled projectors, or a maximum of 108 rounds for the batteries of nine-barrelled projectors. This type of "crash salvo" was a completely new departure in anti-aircraft defence; and in addition to obtaining a reasonable number of kills, the deterrent effect on raiders was very marked.

As in the case of the 2-inch rocket, the motor of the 3-inch anti-aircraft rocket became the prototype of a group of new rocket weapons, some of which will be briefly described later.

THE 5-INCH ROCKET

I have now completed an outline of the development of the 2-inch and 3-inch rocket motors, and of the events which led to the adoption of the 3-inch anti-aircraft rocket by the Army. Before passing on to a review of some of the other rocket weapons that played their part in the recent war, I propose to give a brief description of an extremely interesting rocket motor development, which was destined to form the basis of the naval beach barrage weapon, as well as being employed for a number of other purposes.

It has been mentioned that on the outbreak of war the development of the 3-inch rocket was forced to yield place to other more immediately urgent projects. One of these was a demand for a weapon that could be handled in slit trenches and would be capable of projecting with reasonable accuracy a bomb weighing 30 lb. to ranges varying between 2 and 4 miles. The conditions to be satisfied implied that while the performance of the rocket only needed to be moderate, the accuracy of functioning would have to be relatively high. Further, the handling requirement imposed an upper limit of 6 feet on the possible length of the projector, from which the rocket is launched. In consequence, effort was concentrated on evolving a design of motor which would give the rocket as high an acceleration as possible at launching to ensure stability, and would include precautions

against the ejection of unburnt slivers of cordite at the end of the combustion of the propellant charge. This latter condition was laid down for the design specification, since at the time it was believed that sliver ejection was one of the major contributory causes of dispersion.

The design of motor that was finally evolved is shown in outline in Fig. 5. The diameter of the round was too large to enable welded steel tubes to be employed in the construction of the motor body, and it was decided to use the drawn steel tubing from which the bomb itself was made. The nozzle throat diameter was not large in comparison with the calibre of the round, so that an annulus of some width was left between it and the walls of the tube.

To obtain a quick-burning charge, recourse was had to a multiple-stick design having eleven sticks of tubular cordite. These were disposed in the annular space between the tube wall and an internal axial tube, which was perforated to allow a free flow of gas. The sticks of cordite were slotted radially with the same object in view.

Such an arrangement gives a low ratio of charge weight to rocket weight; and by present-day standards the dispersion of the rocket was not particularly good. Nevertheless, the design was successful, for it had a high performance index (and by this is meant the ratio of the thrust-time integral in pounds-seconds units to the charge weight in pounds, i.e. a measure of the efficiency of the charge and nozzle combination); while the unknown factor entering into dispersion was low.

The rocket met the specification laid down, but as a result of the changing pattern of the war it was never used operationally in its intended role. The motor design, however, had a profound effect on subsequent weapon developments.

SOME BRITISH ROCKET WEAPONS

By the end of 1940, then, we had available three tested and proved designs of rocket motor, of 2-inch, 3-inch, and 5-inch calibre respectively. The first two employed single-stick charges and the third a light-weight multiple-stick charge. From this point onwards until the end of hostilities the major problems that confronted the technicians working on general rocket development were almost all ones of modification, adaptation, and improvement of the three standard types to meet urgent operational requirements; and almost all of the many rocket weapons that were used against the enemy were built round one or other of these three motors.

Time will not permit me to describe to you all these developments, so I must limit myself to selecting typical examples from each group of weapons. I will take them under the following headings:—

- (a) Anti-aircraft weapons of all types.
- (b) Barrage weapons for area softening and mass bombardment.
- (c) Airborne rockets for land and sea targets.
- (d) Rocket motors for assisted take-off of aircraft.

(a) *Anti-aircraft Weapons of all Types.* This group of weapons divides into two categories: (i) rockets carrying an explosive head

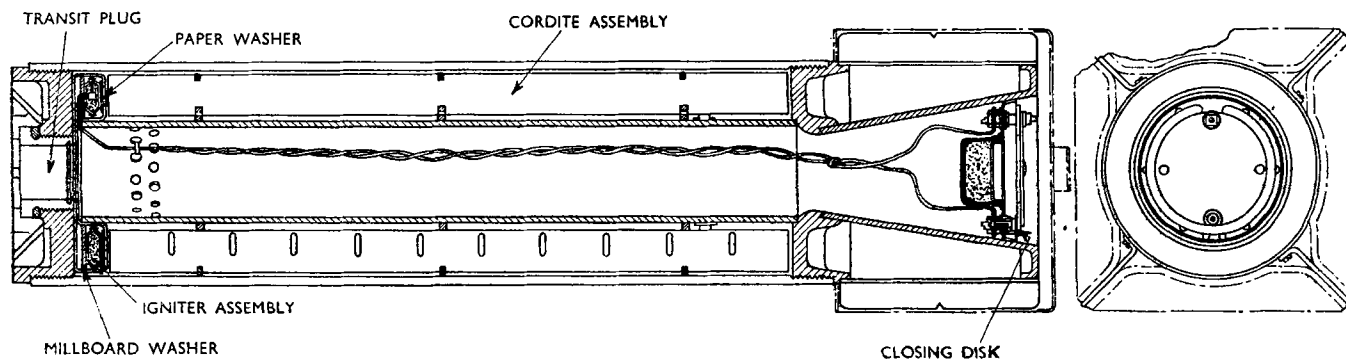


Fig. 5. 5-inch Rocket Motor

detonated either by a time fuse, pre-set according to ground prediction of the instant at which the paths of the rocket and the target aircraft cross; or by a direct-action fuse detonating on contact with the target; (ii) rockets fitted with heads carrying barrage obstruction systems such as the parachute-wire-bomb assembly.

In the first category comes the 3-inch anti-aircraft rocket, which has already been described, and which was mainly employed against high-level bombers. To meet the problem of countering low-level or dive-bombing attacks on naval targets, a multiple-barrel projector, popularly known as the "pillar-box", was evolved.

This projector is shown in Fig. 6, Plate 1. It is handled by one man only, who carries out the operations of traversing, elevating, and firing from a central control cab. The rockets are launched from two banks of ten projectors each, one on each side of the operator. The rockets can be fired in salvos up to a total of twenty rounds before reloading, and are fitted with explosive heads and direct-action fuses which incorporate a self-destruction device. The weapon was used in merchant vessels as well as in naval craft, and was employed also in the defence of harbours and convoys.

As an example of category two, another naval weapon may be selected. This was the first rocket weapon in operational use in the British service, and, indeed, I believe it was the first used by any belligerent in the 1939-45 war. It was designed as a counter to the dive-bomber menace, and such impetus and drive were put into the development that a period of less than eight months lapsed between the statement of the demand for the weapon and its operational use against the enemy.

The requirement was for a rocket to propel an aerial mine into the path of an oncoming aircraft for the protection of ships and harbours. A parachute-wire-bomb device intended for dropping from fighters against bombers was under active development by the Air Ministry. This assembly was modified to enable it to withstand the setback imposed during the acceleration of the rocket and the shock of unspooling at high speed, and a new 3-inch rocket motor was designed to project the assembly to the required height.

It was decided to fire salvos of twenty mines at a time, and a simple multi-barrelled projector capable of speedy manufacture and suitable for mounting in ships was evolved. The mine canister was 7 inches in diameter, so that the arrangement was adopted using a 7-inch diameter drum around the 3-inch diameter motor for stabilizing the rocket in flight. This enabled the rocket to be fired from an open-ended 7-inch smooth-bore tube.

The development was completed by May 1940, and equipments were installed in several ships and on certain British harbours. On the first occasion on which the weapon came into active service during July 1940, a German dive-bomber was brought down.

This was a relatively crude weapon, but it demonstrated the potentialities of the rocket as a carrier of bulky and fragile devices, and the possibility of firing large salvos without unacceptable recoil forces. It was the forerunner of several other wire-carrying rockets, which subsequently came into the British service.

(b) *Barrage Weapons for Area Softening and Mass Bombardment.* One of the most important characteristics of the rocket from the point of view of its employment in war is that there are practically no recoil forces on discharge from the projector. This enables multi-barrelled projectors to be built of light construction, so that a heavy "crash" concentration of fire can be maintained for a short time before reloading. The ability to deliver such a concentration is of the highest importance in certain aspects of military operations, and the rocket offers a solution to the problem with notable economy in transportation and in man-power. This property of the rocket had already been exploited in both anti-aircraft roles; and it formed the basis of the original specification for the 5-inch weapon.

After the experimental raid on Dieppe in 1942 a meeting was held at Combined Operations Headquarters to discuss the lessons that had been learned. The main conclusion of that meeting was that if a landing was to be successful it was imperative that the beaches, and the land overlooking the beaches,

must be drenched with the greatest possible quantity of high-explosive shell immediately prior to the landing. Experience had shown that, in spite of taking every possible precaution to identify enemy batteries and machine guns, in order to render them ineffective by aimed fire from naval guns and aircraft, many of the enemy's weapons could not be located. Further, it was found to be difficult to engage such targets after the attack had been launched as they speedily became obscured by the smoke and dust of battle.

It was decided therefore to investigate the possibility of using special craft fitted with a large number of 5-inch rocket projectors, capable of drenching an area with medium-weight high-explosive shell during the period immediately before the landing.

Work was started on the basis of fitting to the 5-inch rocket motor a high-explosive shell, specially designed to give optimum fragmentation effect, taking advantage of the low setback force from the rocket. A sensitive impact fuse was designed to reduce cratering on impact to a minimum, and the rocket motor itself was modified and improved in certain respects.

The projectors are illustrated in Fig. 7, Plate 1. They were adopted from the sextuple projectors constructed to meet the original Army specification for the 5-inch rocket to fire from a slit trench, and they were fitted in large banks in the craft. Rockets were fired automatically in rapidly successive groups to reduce the chance of mutual interference in flight.

In the form eventually used a single craft was able to fire highly lethal ammunition on the chosen target area at a rate of half a ton a second for nearly a minute at a time.

A typical salvo is portrayed in Fig. 8, Plate 1. The equipment was given the name of "mattress" as a tribute to its softening effect on the enemy. The requirement for the weapon was stated by the Admiralty in November 1942. Development was completed by May 1943, and the craft were first used operationally in July 1943, eight months after the formulation of the requirement. The first operation was to cover the landing on Sicily, and it was a spectacular success. An extract from the report of the Commander-in-Chief, Mediterranean, to the Admiralty reads:—

"It might not be too much to hope that the rocket craft in adequate numbers may even prove the weapon by which the hard crust of North West Europe may eventually be pierced."

After the hard crust had in fact been pierced in 1944, the special correspondent of the *Daily Telegraph* wrote:—

"Rocket ships have been an immensely effective and terrifying weapon, discharging bank after bank of projectiles and blasting the beaches with fire and destruction until it seemed that no living creature could survive."

The Army counterpart of the weapon was now considered, and a specification took shape following improvements in technique which had emerged as a result of basic development. By the end of 1943 the rocket development establishments had evolved a design of projector with spiral rails to give the rocket an initial rotation during its travel on the projector. The rotation was slow, and was insufficient for complete stabilization of the rocket in flight, but it enabled smaller fins to be used. The system had the following advantages:—

- (i) The accuracy was increased, the 50 per cent dispersion zone being reduced by some 60 per cent.
- (ii) The length of the projector rails could be reduced to that of the rocket motor.
- (iii) The shell could in consequence be of larger calibre than the motor, since it could protrude beyond the end of the rails.
- (iv) The weight of the projector could be substantially reduced.

A specification was drawn up for a rocket weapon to have a maximum range of 8,000 yards and carrying the same shell as that used for the naval mattress round. It was realized that variation in range would be required; and to avoid firing at low angles of elevation where the range dispersion is great, reduced ranges were obtained by fitting flat disks of varying diameter over the nose of the shell. These disks were known as "spoilors", and they had the effect of increasing air resistance.

The rocket motor was adopted from the standard 3-inch design; and multiple spiral-railed projectors were designed to be

mounted on a 20 cwt. general-service trailer. This equipment was called the "land mattress", and is depicted in Figs. 9 and 10, Plate 2.

Experimental batteries were sent overseas during the autumn of 1944 and used by the Canadian Army in crossing the Scheldt, and later by the Second Army in crossing the Rhine. The equipment proved to be highly successful in the role of a concentrated barrage weapon, and the system appears likely to have great potentialities for the future in the field army.

There was one occasion when both varieties of the mattress worked in partnership, during the attack on the island of Walcheren. This culminated in an intensive barrage put up by the Army land mattress batteries firing over the heads of the naval rocket craft, which in their turn fired over the heads of the infantry. When the assaulting troops landed, they found that the target had been saturated and the opposition encountered was feeble.

(c) *Airborne Rockets for Land and Sea Targets.* I now come to the extremely important field of airborne rockets for attacking land and sea targets. It was mentioned earlier in this lecture that one of the original objectives for investigation laid down by the Committee of Imperial Defence in 1936 was the development of rockets as weapons fired from aircraft. The Committee had in mind at the time the use of rockets fired from aircraft against other aircraft, but as the tactics of the war developed it became apparent that this was not the immediate requirement. There were other and more urgent needs; in particular the attack of tanks on land and of submarines at sea. The successful attack of both these types of target demanded hitting power far beyond that of any gun armament that could be accommodated in the aircraft structure.

Systematic study of the problems involved was started during the summer of 1941, using a modified form of the 3-inch motor as the propelling agent in conjunction with a solid armour-piercing head, and the first trials to test the projector equipment and the general functioning of the rocket were carried out in October 1941, using a Hurricane aircraft. This early design was intended for use against tanks, but shortly after the first trials the suggestion was made that the weapon might be effective against submarines; a target which at that time was of greater importance than tanks for the success of our arms.

Accordingly both roles were investigated, and finally the armour-piercing type was adopted for the anti-submarine role after a prolonged spell of design and experiment, culminating in full-scale trials at Government ranges. In December 1942 a comprehensive report on the trials was issued by the Air Ministry, in which it was concluded that the weapon was "capable of making very accurate and devastating attacks on the U-boats". It was introduced into both the R.A.F. and the Fleet Air Arm during the spring of 1943, and each service had immediate successes. The first submarine to be sunk by rockets fell to a Swordfish aircraft flown from H.M.S. *Archer* in April 1943. Within a matter of days, the R.A.F. had its first success in the Mediterranean.

Concurrently, work had been continuing on the anti-tank role; and success was achieved using a high-explosive shell weighing 60 lb. Rocket-firing aircraft were used extensively against land targets from 1943 onwards with telling effect; in particular they were an outstanding contribution to the success of the battle of the Falaise Gap, one of the turning points of the war. The rockets were found to cause considerable damage to light defences and vehicles, as well as to tanks. While perforation of the armour of the tank could not be achieved with the high-explosive shell used, the aircraft was able to attack from any direction and against the most vulnerable parts. The effect of a direct hit was usually to cause fire or disablement; frequently even a near miss was sufficient to induce the crew to abandon their tank.

In the majority of cases aeroplanes were fitted with eight launchers, from which the rockets were slung, four under each wing of the aircraft. The loading operation is depicted in Fig. 11, Plate 2, and a typical salvo firing in Fig. 12, Plate 2.

The rockets were launched in pairs, so that it was possible to fire four salvos of two rounds each or any combination up to eight rounds at a time. The hitting power given to the aircraft

by the full crash salvo was very greatly in excess of anything that could be achieved by gun armament; it was, in fact, momentarily the equivalent of the full firing power of a medium cruiser.

As a result of the successes achieved by our aircraft, airborne rocket equipments were adopted by the United States Forces, using British rockets until they later evolved their own designs.

(d) *Rocket Motors for Assisted Take-off of Aircraft.* My last example will be the use of rocket motors to assist heavy aircraft to take-off from a short runway. This was again one of the original objectives laid down by the Committee of Imperial Defence, and although it never came into the limelight of publicity to the extent that other rocket equipments were so favoured, it proved to be a highly important contribution to the general war effort.

It is a matter of difficulty, and in some cases a matter of impossibility, for aircraft to take-off from ships without assistance, as the length of runway is insufficient. For example, to fly a fighter aircraft off a ship moving at 10 knots requires a free runway of about 400 feet if the aeroplane is unassisted.

Some years ago a system of catapulting aircraft had been introduced, whereby the normal acceleration of the aircraft was increased and the runway necessary was reduced by approximately 75 per cent. The catapult was operated by a wire purchase system, power being provided by gas pressure from the explosion of a cordite charge in a chamber somewhat similar to the chamber of a gun.

Soon after the outbreak of war it became imperative to provide merchant ships with fighter aircraft to engage hostile bombers, and for this purpose the installation of catapults in ships of relatively light construction proved undesirable. During 1940, therefore, the problem was investigated of providing rocket assistance during the take-off. Two systems were finally evolved. The first, known as the "C.R.C." (cordite rocket catapult), employed rocket motors for driving a trolley on which the aircraft was carried. This device had points of similarity with the original catapult system, but was a great improvement in that the apparatus was much simpler, and there was practically no recoil effect on the ship's structure. The second system, known as the "A.T.O." (assisted take-off), was a rocket propulsion unit which was carried on the aircraft itself, and jettisoned after the aircraft became airborne.

The C.R.C. system was the first to be completed, and it was used with conspicuous success, enabling merchant convoys to send up fast fighter aircraft to combat approaching bombers. It had the limitation, however, that only one aircraft could be put up from each ship. With the advent of escort carriers, aircraft were flown off the flight deck by means of the A.T.O. system, and the C.R.C. system gradually became superseded. A feature of both systems was the extreme reliability of action throughout the period of their use in the war.

CONCLUSION

The weapons that have been described in outline by no means represent the full tally of what was achieved in rocket development between 1936 and 1945, but they illustrate the extent and the variety of the several applications of rocket weapons that were devised to meet military requirements. You will note that in all cases propulsion was by solid fuel, and that no mention has been made of rocket motors designed for use with liquid-fuel systems.

A substantial amount of effort was, in fact, devoted to this field, and very real progress was made, which will be of great value for future development. The knowledge that was accumulated during the war of the technique of liquid-fuel propulsion also enabled us to assess the potentialities of German weapons of this type, and to predict the effect to be countered when they were used in action against us. Nevertheless, the British Forces for various reasons never actually employed liquid-fuel rockets for warlike purposes; and I have therefore regarded them as outside the scope of this lecture.

One feature of the story that I have told will not have escaped your notice; and that is that in practically no case did the finished article follow the original specification for use, nor was it

employed in the role for which it had first been intended. This was in part due to the rapidly changing aspect of the war, and to the impossibility during the early stages of the conflict of predicting with any confidence the next phase. A certain amount of improvisation and extemporization is inevitable in such circumstances. There were, further, the difficulties which always hedge round a pioneer field of development such as the rocket. The technician has no fund of accumulated experience on which to draw, as in the case of established types of weapons; while the user is naturally reluctant to take a chance, except either as a last resort or if the prize offered for success is great.

At the start, practically all that the rocket development group had to offer were faith and hope; we were fortunate in receiving a modicum of charity; and later we gathered to ourselves zealous and active helpers as the potentialities of rocket weapons came to be appreciated. This help came from all quarters; from the fighting services themselves, from the scientific and engineering professions, from the production departments, and from the various branches of industry on which demands were made.

While acknowledgement is due to all these associated groups for the important contributions they made towards the results that were obtained, there is one group to which I should like to pay particular tribute, and I feel that this is a fitting occasion on which to do so. I refer to those responsible for the production of rocket components and rocket projectors, both in the Government production departments and factories and in industry.

When, as frequently happened, a period of a few months only elapsed between the start of a new development and the introduction of the finished weapon into the Services, it follows that production had to be started on the basis of unfinished designs. Such a situation is, quite properly, anathema to any right-thinking engineer, and immensely complicates his task. On many occasions

I have been castigated by my colleagues responsible for production in terms which from their simple directness and pungency of expression left no room for doubt as to their opinion of my behaviour. Invariably, nevertheless, they then proceeded to do their best; and how good that best was is manifest from the record of what was achieved.

The rocket has come to stay, and is destined to exert an influence on the general array of warlike material that will increase sharply with the passage of time. As yet, it is in a comparatively early stage of development, and the full extent of its possibilities can only be dimly envisaged. A wide field will be opened up by the application of extraneous methods of control to the rocket flight, together with the development of its performance and range of action. This aspect of warfare, to which the Americans have applied the felicitous description of "push-button warfare", will revolutionize our strategical and tactical conceptions if it can be successfully developed. The technical difficulties to be overcome are immense, and should not be under-estimated; a thorough exploitation of this new field must necessarily make heavy demands on our available resources.

Whatever progress is made, however, in the development of guided missiles there will always be room for the "unguided" or free-flying rocket; particularly if the accuracy can be brought to the same order as that of the shell fired from ordnance. The improvement in this respect that was achieved over the period of development I have outlined was marked; and the exploration of new technique both of rocket motor design and of methods of stabilization may be confidently expected to yield the desired results.

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