LONDON'S NEW AIRPORT

NEWNES

PRACTICAL MECHANICS

9D.

EDITOR: F. J. CAMM

MARCH 1949

Rocket Propulsion

Rocket-assisted Take-off : Successive-feed Powder Motors

By K. W. GATLAND

(*Continued from page* 176, *February issue*)

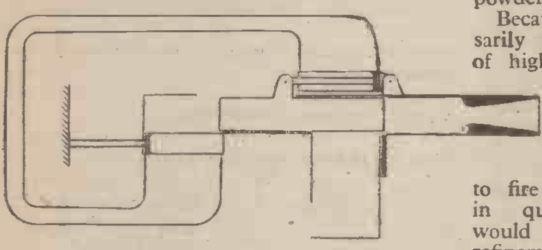
A GREAT deal has already been said of the development of successively loaded powder motors, but the units concerned have largely been the outcome of research in the U.S.A.

In Britain, similar research has been conducted by the Astronautical Development Society, and this has involved investigations of the recharging mechanisms for both the slow-burning and rapid-burning powders.

The principal difficulty associated with powder fuels has always been their limited duration of firing, and in the development of the successively loaded motor much hope is held to remedy this deficiency.

Assisted Take-off Rocket Units

The use of rockets to assist fighter aircraft and heavily laden bombers and transports



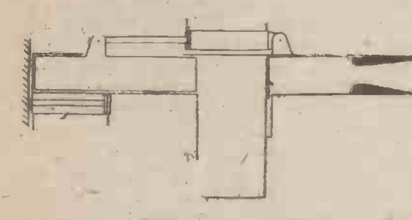


Fig. 56.—Diagrams showing two positions of an improved cartridge injector.

into the air without the need for long runways is to-day common knowledge.

Almost without exception the units employed are simple cordite rockets. The standard charge contains 26lb. of propellent within a steel casing of about 40lb. weight, 40in. long and 5in. in diameter, with a $\frac{1}{8}$in. wall thickness. Short nozzles are fitted, 4in. in length, the throat to mouth diameters enlarging from approximately 2in. to 4in.

The thrust yield of these charges is slightly more than 1,000lb., and the energy per lb. of cordite, therefore, a little greater than 41lb.

The rockets are mounted in batteries of two to four, generally either side of the fuselage, close in to the wing roots. They are usually capable of maintaining a thrust constant for about four seconds, and, once expended, automatically release from their mountings and drop away.

In trials carried out in the U.S.A., a navy *Avenger*, was fitted with four "Jato" assisting rockets, each capable of a thrust of 330 h.p., and it was found that these cut down the take-off run by as much as 60 per cent.

It is of interest to note that the Sander 10lb. powder charges, used by Fritz von Opel in his rocket glider of 1929, each developed a thrust of 53lb., effective for 25 seconds. Other single charges produced by Sander were capable of thrusts exceeding 600lb., but only for three or four seconds.

A high thrust, it will be appreciated, is only possible at the expense of the effective thrust duration and the burning rate can be moderated by the type and consistency of the powder employed.

Because of the necessarily limited duration of high thrust powder charges, it is obvious that some form of constant feed device, able to fire several charges in quick succession, would be a valuable refinement. Before going on to discuss units of this kind, however, a word about an interesting liquid fuel accelerating gear, developed in 1943 and used extensively by the Luftwaffe.

The Walter Bi-fuel A.T.O. Gear

The Germans sought to overcome the limitations of the powder charge by the use of a bi-fuel assisted take-off unit, known as the Walter 109-500.

The device employed 80 per cent. pure hydrogen peroxide with a permanganate catalyst, the peroxide being contained in a spherical tank and fed to a single combustion chamber under pressure from air bottles. Its fully charged weight was only 600lb.

The motor operated at an average thrust of 1,200lb., the power lasting from 24 to 28 seconds.

Two of these units were fitted, one below each wing, being jettisoned and parachuted to the

"Strut Psychrometer." An instrument used on meteorological aircraft for recording pressure, temperature, and humidity.—Courtesy of the Meteorological Office, Air Ministry.

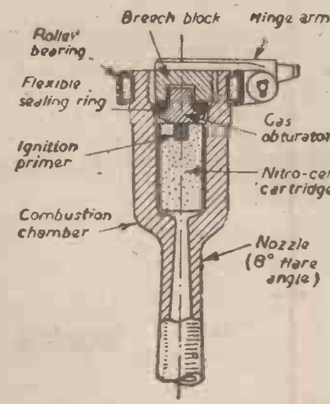


Fig. 58.—Detail of firing chamber and seal mechanism of rapid fire "cartridge" motor.

ground for re-use, once combustion had ceased. Since only "chemical combustion" took place within the chamber, the same unit, recharged, could be used several times before corrosion took serious effect.

A modified version of the Walter 109-500 was fitted in the Hs. 293 "glide-bomb," used for attacks upon Allied shipping.

A Successive Feed Motor for Slow-burning Powders

An outline of the more critical design problems to be overcome in the evolvement of a suitable device has already been given in the references to Professor Goddard's early researches with rapid-burning powders (PRACTICAL MECHANICS, August, 1945, pp. 373-4), and it will be recalled that, although much in detail has been previously conducted concerning chamber and nozzle efficiencies, information is entirely lacking of the reloading mechanism itself.

Work towards evolving a small motor, capable of the repeated injection of quantities of slow-burning powder to a single combustion chamber, was commenced in 1941, and credit for this and subsequent development is largely due to Mr. A. M. Kunesch and the writer. The outcome of an initial survey was a first self-operating design in which powder fuel was intended to be fed in the form of "cartridges" (Fig. 57).

With reference to the diagram, it will be seen that the unit is made up of the following components: combustion chamber, door, breech, cartridge, pump, pneumatic jack, and injector rod.

The "injector" was designed around a specially prepared "plastic cartridge" which had no separate case and burned away com-

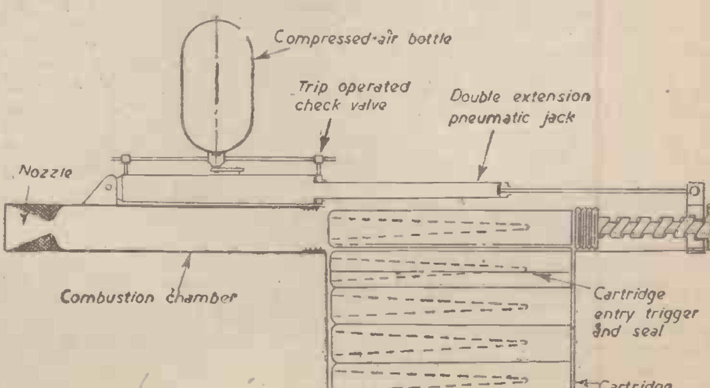


Fig. 57.—The improved cartridge injector for slow-burning charges (Astronautical Development Society, 1943).

pletely. The desired structural form resulted from an organic admixture to certain fuel powders, and using this process it was found that rocket propellents could be formed readily into any desired shape or size.


Two views of an experimental rocket motor to the design for a rapid-firing cartridge injector. It has been used as a proving motor for testing single charges. (Astronautical Development Society, 1943).

Experiments with charges of this nature have shown that no residue remains after firing, it being found that ash produced in combustion only condensed outside the nozzle. This is particularly important in view of the fouling which occurs after the firing of gunpowder, and which would seriously impede the proper function of a repeating mechanism.

Apart from the special powders tested, it is also possible to bond nitro-cellulose powders—cordite, for instance, may be conveniently formed by the admixture of acetone.

An impression of the "injector" can be best gauged from an explanation of its operation. The firing sequence is as follows: a cartridge is initially primed to the combustion chamber when the "reaction carriage" is at its foremost travel—as shown in Fig. 56. The chamber seal door is then closed by a cam action and the cartridge fired, causing the complete unit to recoil along runners to a bearing plate. During this action air pressure is transferred from the supply pump (situated beneath the carriage) to the pneumatic jack, which actuates the injector rod and retains it at the rear of the carriage. A second cartridge is then free to enter the breech.

Once the thrust of the primed charge has fallen below a certain value, recoil springs return the carriage to its original position, pressure being transferred back to the supply pump, while air is forced out into the other side of the injector jack to move the rod forward. The door is then rapidly opened and closed to allow the second cartridge to enter for combustion. From this point the operating cycle is continued automatically.

The conclusions of the initial survey gave clear indication that the two types of powder—slow and rapid burning—would require entirely different injection mechanisms. In view of this, it was decided to proceed first with the slow-burning powder motor as the system originally developed was obviously not suitable for rapid firing.

An Improved "Cartridge Injector"

The second design was prepared in more detail and presented an altogether more practical solution. Perhaps most important of all, the effective sealing of the firing chamber—a problem ignored in the early design—was most satisfactorily overcome. Another refinement was that the recoiling feed action was eliminated.

The improved "cartridge injector" (Fig. 56), though basically the same as the original, incorporated several entirely new features. It comprised the following main items: combustion chamber, breech, cartridge entry chute, cartridge entry trigger and chute seal, pneumatic jack, check cocks (two required), compressed air cylinder, and breech block/injector.

As may be gathered from the diagram, the motor is designed to operate under controlled pressure from an air bottle. The air is fed through trip-operated control cocks which alternately direct pressure to move the breech block/injector backwards and forwards under the action of a pneumatic jack. As will be seen from the diagram, the breech block, which seals the chamber, also forms part of the injector movement.

At the rearmost travel of the injector a cartridge is allowed to enter the breech. The air pressure is then applied to return the jack piston, which pushes the injector forwards and inserts the charge. The breech block at the injector head is then screwed in to seal the combustion chamber under the action of the "Archimedes screw," and the cartridge electrically fired.

Immediately the thrust of the charge commences to decline, pressure from the air bottle moves the jack piston backwards, and the injector head automatically unscrews and travels to the rear, allowing a further charge to rise into the breech.

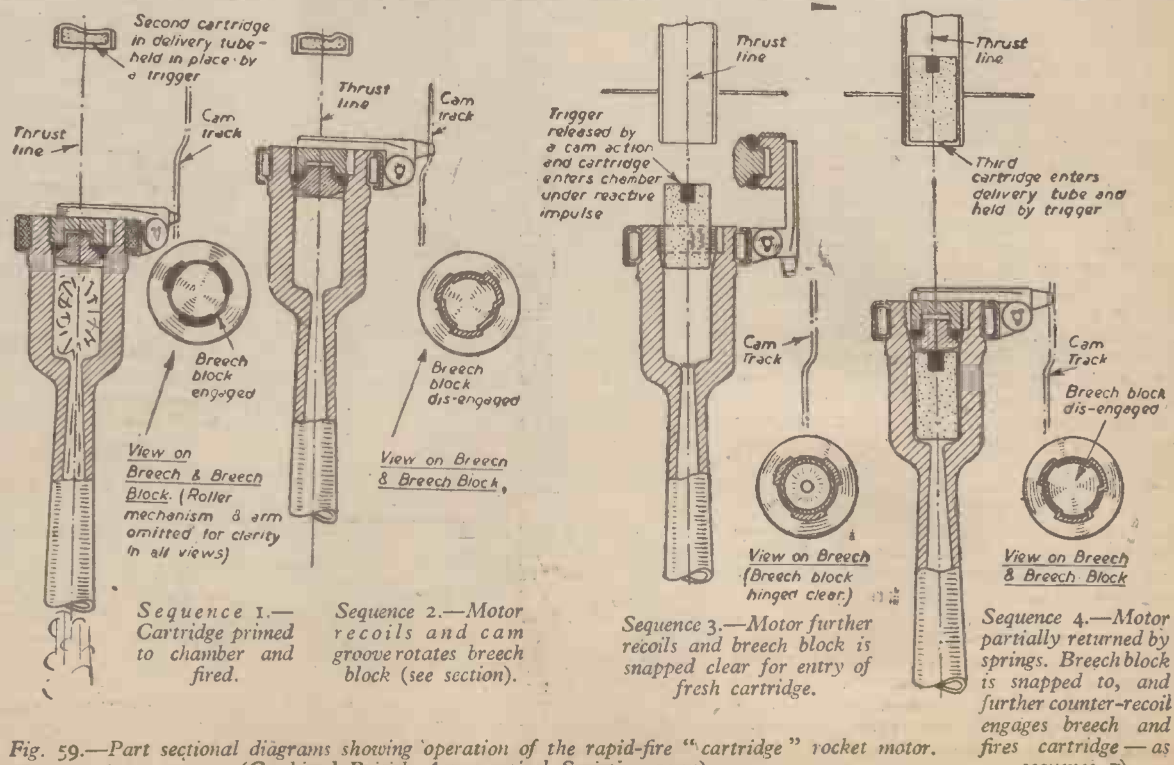
It would probably be necessary to incorporate vents around the chamber seal to prevent "blowback" of thrust pressure as the chamber is opened preparatory to the injection of a fresh charge. Otherwise, the gas temperature may be sufficient to ignite the charge before its entry into the chamber. The unit described is intended to fire five three-second cartridges, but for units employing more charges it would be necessary to jacket the combustion chamber with liquid coolant.

Whether or not an A.T.O. system of this type would be preferable to fixing the same number of single charges to fire in sequence is debatable. The one principal advantage of the reloading device is that the thrust line is constant, and as reloading would be almost instantaneous, the whole question largely resolves into a matter of reliability, weight and installation space.

The Rapid-fire Rocket Motor

The rapid-firing cartridge motor is altogether different from the units previously described, having been designed to power a light, high-altitude sounding rocket.

In this arrangement the cartridges are fed at the rate of 20 per second, but each charge weighs only ⅛oz., as compared with the charges of several pounds specified in the slow-firing designs. Because of this, the mechanism which feeds the cartridges can be appreciably lighter, and it is this factor that largely accounts for the high rate of fire. It has, in fact, been estimated that



Sequence 1.—*Cartridge primed to chamber and fired.*

Sequence 2.—*Motor recoils and cam groove rotates breech block (see section).*

Sequence 3.—*Motor further recoils and breech block is snapped clear for entry of fresh cartridge.*

Sequence 4.—*Motor partially returned by springs. Breech block is snapped to, and further counter-recoil engages breech and fires cartridge — as sequence* 1).

Fig. 59.—*Part sectional diagrams showing operation of the rapid-fire "cartridge" rocket motor.* (*Combined British Astronautical Societies,* 1944).

the total weight of the moving parts would not exceed 15oz.

The combustion chamber (Fig. 58) is designed to recoil along runners, and the cartridges are fed by the inertia. There is an opening breech-block to allow the cartridges to enter the chamber, which is rapidly opened and closed under the action of a cam mechanism operated by the recoil.

The chamber is returned by strong springs which compress as the motor recoils under thrust, and the charges, having separate ignition primers, are fired electrically by a simple "make and break" circuit.

The breech-block is constructed with interrupted threads. This enables the breech to be disengaged and re-engaged by a slight turn of the roller bearing to which the hinged arm of the breech-block is attached.

The Combustion Chamber and Nozzle

The combustion chamber is particularly small, its internal length being only 1in. by ½in. diameter. These surfaces are finely machined and polished to reduce frictional losses, and thus any excessive heating of the chamber is avoided.

A high operating efficiency is therefore maintained over the entire period of combustion, and while it is rare for a liquid-fuelled motor to greatly exceed a chamber pressure of 500lb./sq. in., the rapid firing "cartridge" motor is designed to permit the exceptionally high pressures of 30 to 45 *thousand* lb./sq. in.

This largely accounts for the high efficiency, which is, of course, due to the rapidity of combustion and the greater expansion and less dissociation of the gases.

To suit these conditions the size of the motor is limited, but, nevertheless, the dimensions of the unit here discussed are well within the bounds of the practical. Indeed, the thermal efficiency would be improved by slightly "scaling up" the chamber, due to the reduced heat loss. This is because the chamber area increases by four to the weight of the charge, eight times.

A high-expansion tapered nozzle, 7.25in. long, is fitted which embodies an 8 degree flare angle, expanding from .125in. at the throat to slightly more than 1in. at the mouth. It is not quite a straight taper, as at the mouth end the angle is decreased to form a short parallel length, and this refinement—originally adopted by Professor Goddard—ensures that the high-velocity gases fill the cross-section throughout the entire nozzle length. Without this change in contour a discontinuity of flow would be produced at the points where the gases leave the wall of the nozzle and result in the formation of eddies with a consequential loss of unidirectional velocity.

In comparison with the machine-gun—a useful guide in this work—heating effects would be less critical. In the gun the bullet creates considerable friction and confines the propelling gases in the barrel (at a temperature of 2,000 deg. C.), whereas in our particular case there is no friction save that of the gas itself, which escapes almost instantly.

It is thus obvious that the rocket motor will permit the firing of considerably more cartridges than a machine-gun before getting to *critical heat*—the temperature at which the propellent is ignited merely by contact with the combustion chamber.

Explanation of Diagrams

The diagrams (Fig. 59) represent the firing sequence of the motor, and is self-explanatory. Sequence "1" shows the motor as it appears at its rearmost travel, a cartridge having just been fired. The breech block is, of course, engaged in this position, and a fresh cartridge is held in place at the bottom of the feed tube.

In the second view the motor is shown partially recoiled, and it will be seen that the breech-block has been rotated so that it is completely disengaged under the action of the cam track.

The third sequence depicts the motor in full recoil, with the breech-block snapped clear and the feed trigger released to allow the second cartridge to enter the chamber under the inertia of recoil.

Finally, the motor is shown partially returned by the recoil springs (these are omitted in the diagram), the breech-block being snapped to, but the threads not yet engaged in the breech. At this point a selective mechanism allows a third cartridge to enter the delivery tube.

At the rearmost travel the motor appears again as sequence "1," the breech-block re-engaged, and the second charge fired as the first.

Performance

Previous tests of single-shot motors of similar chamber and nozzle forms have shown that it is reasonable to expect jet velocities of 7,000 to 7,500ft./sec., and since the chamber proposed is somewhat larger than the test types, the maximum figure should be nearer the mark.

Using ⅛oz. cartridges, the jet flow works out at 2½oz. per second, and assuming a jet velocity of 7,500ft./sec., the thrust would be approximately 36lb. Although the jet flow and thrust values are not great in comparison with other motors, the fact that the chamber is of midget proportions and the complete unit so very light ensures a high operating efficiency.

A Solid-fuelled Sounding Rocket

The possibilities of the unique cartridge motor in a sounding rocket arrangement are illustrated in Fig. 60. As will be seen, the unit can be very compactly accommodated, and there appears no reason why such an arrangement should not prove highly effective.

The combustion chamber of the bi-fuel Walter 109-500 assisted take-off unit described in this article. Note the helical mixing vanes around the central support tube. The propellent enters through a stainless steel nozzle at the head, and thrust is derived through chemical reaction resulting from H_2O_2 and calcium permanganate.

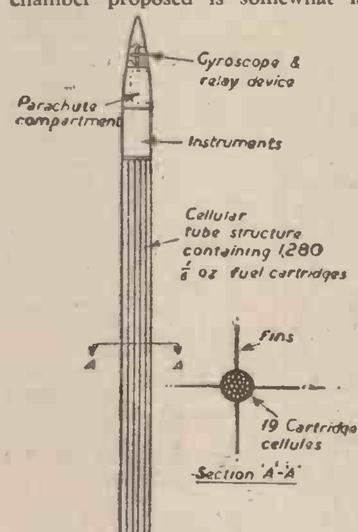


Fig. 60.—Suggested layout for a successively loading "cartridge" rocket.

In the projected design the fuel container comprises 19 individual ½in. i/dia. cellules, arranged on a honeycomb plan for maximum structural strength and fuel capacity.

Basing the size of the rocket on 10lb. of fuel (or 1,280 cartridges), it should be possible to build the cellules and shell of bonded plastic, as affording a ready finish and greater resistance to denting than a much thinner metal case and tube structure of the same weight. A plastic case and the desired number of cellular feed tubes would weight about 5lb.

The motor, having a weight of 2lb., plus 1lb. of instruments, makes the total for the main components in the region of 18lb.

The rocket would have an initial acceleration of 1g., and a final acceleration of approximately 3½g., and, using 1,280 charges, the firing duration would be 64 seconds.

(To be continued)

AUTOMATIC GUN COCKER

A NEW device which has been submitted to the British Patent Office concerns guns in which cocking during firing is effected automatically by gas pressure obtained from the barrel of the gun.

In the larger guns, it is stated by the inventor, after the supply of ammunition has been exhausted and a fresh supply has been introduced, the initial cocking cannot be effected by hand. It has been subjected to pneumatic treatment, but this method, asserts the inventor in question, is somewhat complicated.

The object of the new device is an improved and simplified means for the initial cocking of the gun.

The invention comprises a hydraulic pump supplying pressure fluid to a cylinder containing a plunger which performs the cocking operation. There is also a plunger-type automatic valve loaded through a lever having two positions: (1) where the valve is closed and loaded against the pump delivery pressure and (2) where the valve opens a by-pass passage to release the pump delivery pressure and is not loaded to return to its service position, so that such return must be effected by hand.