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# PRACTICAL MECHANICS

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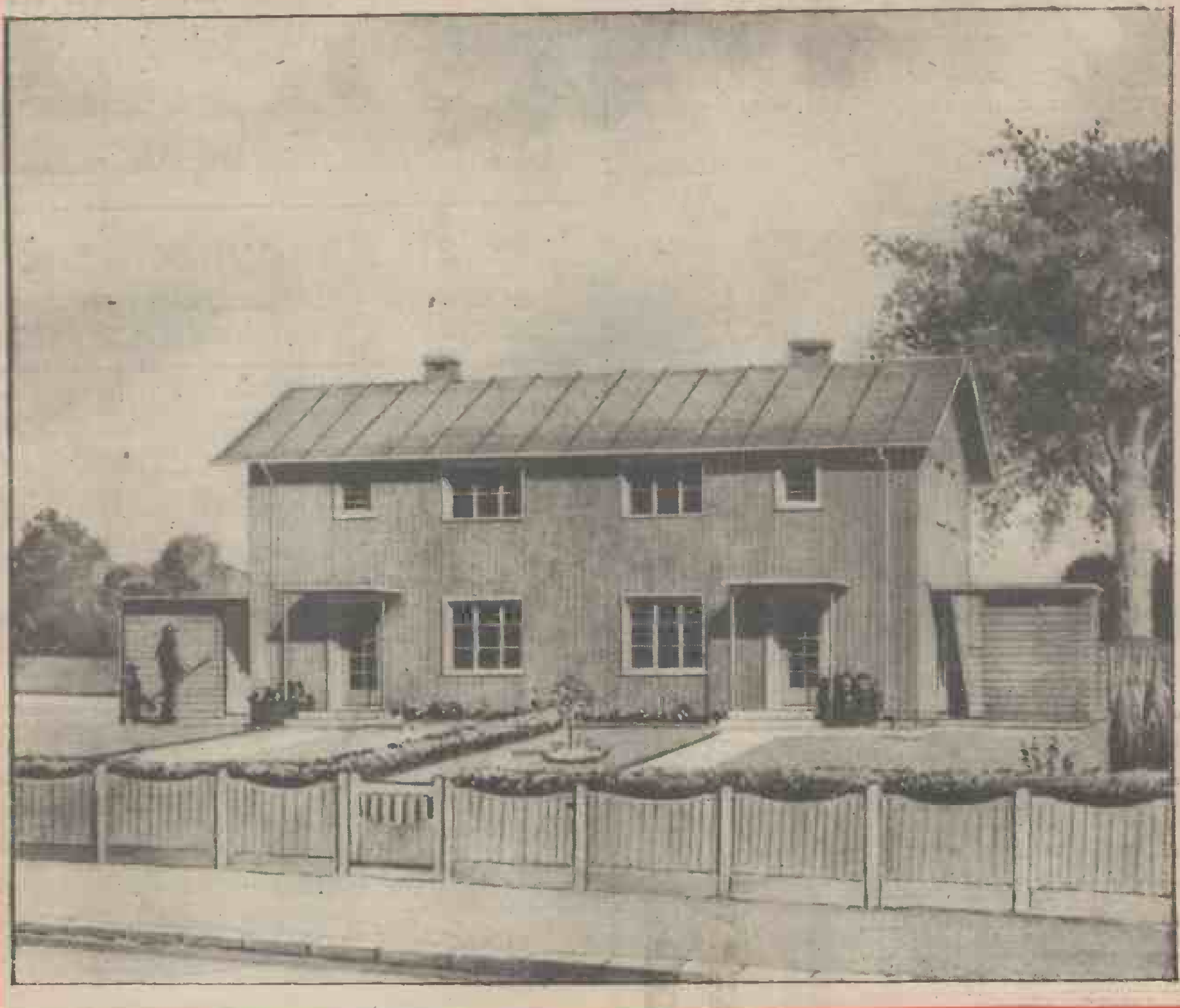

# Rocket Propulsion

## Further Details of German Development : Rocket Research in Scotland : War Rockets in Spain

By K. W. GATLAND

(*Continued from page 158, February issue*)

APART from his work concerning high speed aircraft forms, Sänger also carried out an extensive series of rocket motor tests. These he commenced in 1931 under the auspices of the University of Vienna. As the result of this work, a reaction unit of distinctive performance was developed; one capable of continuous function for periods of anything up to 30 minutes. A diagram of the Sänger constant-volume motor unit is shown in Fig. 17 and leading dimensions are as follows: Combustion chamber, approximately 2ins. spherical diameter; exhaust nozzle, length 10ins.; throat diameter, .25ins.; mouth diameter, 2ins. The motor and the nozzle throat were surrounded by a coolant jacket, the oxygen and fuel both entering the combustion chamber at the motor head. A light diesel fuel oil was employed as fuel. Prior to entering the combustion chamber, the fuel was passed through the jacket as coolant fluid, and forced from the tanks by means of a Bosch type diesel injector pump. The fuel-feed operated at exceptionally high pressures, ranging between 450 and 2,200 lb./sq. in. Because of the high injection pressure, the combustion chamber received additional strength through the transmission of combustion stresses to the outer casing of the coolant jacket, via the high pressure fluid. With this point in mind, Sänger was able to design the combustion chamber with a minimum safety factor; and as a result, the chamber walls were quite thin.

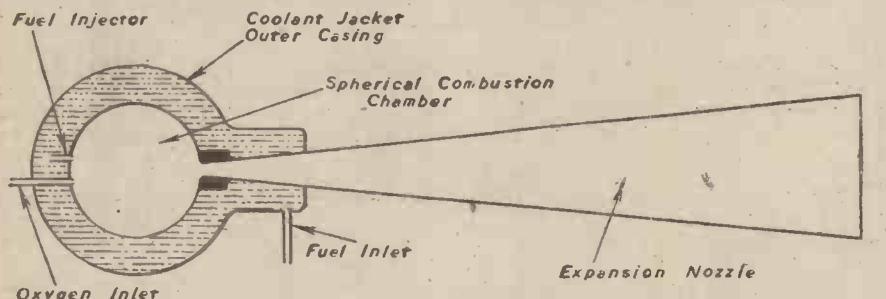


*Fig. 17.—Diagram of experimental constant volume rocket motor developed by Dr. Eugen Sänger.*

The motor was tested on a simple proving stand, the thrust being indicated on a spring recording device. On several occasions, the motor developed a thrust reaction in excess of 55lb—the exhaust velocity varied between 6,600 to 11,500 ft./sec. During certain tests, compressed oxygen was employed in lieu of the liquid form.

### British Research

The early development of rocket propulsion in Gt. Britain owes much to a group of enthusiastic engineers who carried out extensive experimentation in Scotland during the 1930's.

However, their initial investigations and rocket trials date back to the 1914-18 war period, when preliminary work was conducted on the raising of the rocket's efficiency by the use of *thrust augmenters*. During these primary trials it was found that the developed thrust of a rocket projectile, fitted with a venturi augmenting device, could be almost double that of a "free-jet" rocket of identical mass.

The thrust augmenter is merely a device employed in atmosphere to "augment" the mass flow of the rocket efflux, by the injection of atmospheric air into the combustion exhaust stream. It should be noted that if the rocket motor were able to function with anything approaching 100 per cent. efficiency, the thrust augmenter would be of no value because the exhaust gases would be at a minimum temperature upon emerging from the nozzle mouth, and, therefore, incapable of heating the inducted air. The injection of air into the gas stream should preferably be made before expansion is complete, allowing for further expansion after the air and efflux gases are mixed.

For the efficient function of the thrust augmenter a proportion of the heat energy of the fuel is utilised in raising the mass of inducted air to jet velocity, thereby reducing the amount of energy available for conversion to kinetic energy in the efflux itself. The net result is that there is produced a low velocity, high mass, efflux of burnt fuel and inducted air, instead of the high velocity, low mass, efflux of the un-augmented rocket power element.

### Small-scale Rocket 'Plane Experiment

At Glasgow, in 1920, a demonstration was given of a simple tail-first model aeroplane propelled by a single powder-rocket charge. The 'plane flew for a distance of nearly three miles in the phenomenal time of *one minute*.

The fuselage of the model was merely a cardboard tube, 3ft. in length, and of constant section, 4ins. diameter. The propellant charge was contained within a steel-cased cylinder supported inside the fuselage tube at the aft end, and so placed that relative air entering at the nose flowed around the power charge, and passed out through the rear. The special nozzle had a jet discharge of 40 grains per second.

A mainplane of lifting section—4ft. span—with no dihedral, was fitted at the rear, while the horizontal stabiliser was similarly attached at the nose. Both aerofoils were "parasol" mounted, their mounts functioning as vertical stabilisers.

### Intensified Research in Scotland

As the result of further experiment, more advanced types of rocket-powered model aircraft were produced. One particular model, fitted with a float attachment, was tested out across Loch Lomond and flew for more than five miles.

The persons mainly responsible for this further research were G. Aldred Roberts, J. J. Smith, J. Dennis, and, later, P. Blair—a specialist of military rockets. Their prime aim was to produce small-scale, ultra-high-speed rocket aircraft by the development of thrust augmenters.

In order to overcome the many difficulties imposed by working close to habitation two separate experimental sites were set up in open country—one in Cumberland, the other in Sutherlandshire. At these two places the group erected workshop buildings, and there, making use of most limited building resources, a great number of small-scale rocket aircraft and projectiles were constructed.

One of the first undertakings of the group after the completion of the experimental sites was the building of a large, rotary type, proving stand. With the aid of this very necessary apparatus a great number of individual ground tests were performed. Details of performance were derived by means of a stroboscopic device for direct optical observation; and also a small recording cine-camera.

However, before relating details of the subsequent experimentation, a word about the propellant used. For technical reasons it was decided to employ "gunpowder" charges, and these were obtained commercially. Their manufacture followed the usual practice of pyrotechnics in that water in the charge served to minimise the risk of explosion, and the incorporation of linseed oil and lead oleate mixture limited the rate of evaporation. By this method it was made possible for complete rocket units to be kept in store for quite lengthy periods with a reasonable degree of safety.

As a further precautionary measure the rocket unit—consisting of a thin steel case and metal nozzle—was so designed that excessive pressure—about 400 to 500lb./sq. in.—would split the casing at the nozzle attachment (see Fig. 18), and thus merely

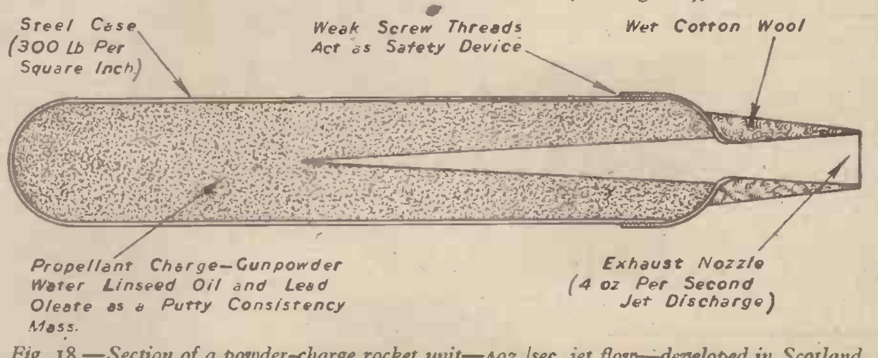


*Fig. 18.—Section of a powder-charge rocket unit—4oz./sec. jet flow—developed in Scotland.*

result in a mild explosion that did no serious damage.

In practice, the charges had to be made at least a week before use, and they would remain safely effective for three or four months. Many of the charges kept beyond this period either exploded, or, when put to test, failed to develop sufficient pressure to function the augmenter system with any degree of efficiency.

These brief observations serve to add further emphasis to the points already stressed regarding the severe instability of pre-mixed fuels.

### Test Results

The rocket trials themselves were mostly made in conjunction with the proving stand. In these experiments the rocket unit under test was fired from a "starter tube." This was merely a tube of constant section—closed at one end—with an internal bore something in excess of the external diameter of the rocket unit. The principle of the "starter" is simply that the rocket, during its passage through the tube, serves to induct air through the tube "mouth," due to an initial vacuumatic effect created by the rocket exhaust within the tube. The air drawn into the tube is expanded by the rocket efflux, resulting in high pressures acting on the rear of the projectile to "push" it from the muzzle, much in the same way as a shell fired from a gun.

Most of the tests of units with augmenter attachments were made on the rotary apparatus, and during the course of numerous firings several highly conclusive figures were obtained of relative efficiencies in the employment of single and multi-stage augmenters. In the great majority of cases the entire augmenter attachment was torn off by the high velocity air flow. During one particular experiment, in which a three-stage augmenter was tested, the third stage was broken away at about 350ft./sec. The second and first stage augmenters were likewise torn off at velocities approximating to 800 and 1,000ft./sec., respectively.

### Nozzles

Three type sizes of nozzle featured in the early work. The smallest used—40 grain/sec., jet flow—was designed for use with a charge case, 10ins. in length, and 1.5ins. internal diameter, which housed a propellant charge slightly in excess of 8 ozs. Another size nozzle—½ oz./sec., jet discharge—was fitted with a case, 5ins. long and 3ins. diameter, and contained a powder charge of just over 1lb.

The 40 grain/sec. rocket unit, without augmenters, developed a thrust of approximately 1lb. With augmenters fitted, the same unit proved itself capable of a consistent thrust of 6lb., and in one particular test a 40 grain/sec. augmented unit achieved a thrust of 10lb.

The larger type nozzles were ribbed externally, and, on test, wet cotton wool was pressed around the outside, which served as coolant for the vulnerable nozzle "throat." Used in conjunction with augmenters, this cooling system was only called upon to function during the first few moments of a firing run, after which the forced draught—due to the augmenter—served to remove the burnt wool, and, subsequently, cool the nozzle by air flow. The 40 grain/sec. nozzle, however, had no initial water cooling. Instead, a thin spun monel-metal jet was fitted. Otherwise, the nozzles were machined wholely from pure copper, although cast aluminium was also tried and found quite satisfactory.

### Rocket-assisted Bi-plane

As a demonstration of the capabilities of a small rocket unit fitted with augmenters, a suitable unit was fitted to a D.H. Tiger Moth, and by its aid was successfully assisted into flight. The device had an overall length of 11ft., and was 1ft. 10ins. in diameter, weighing just over 33lb. Merely 1*lb.* of propellant powder supplied the propulsive jet, and the unit, in complete operation, developed a reactive thrust of 150lb. up to 50 m.p.h. The power rating fell to only 100 h.p. at 100 m.p.h.

The Scottish group attribute these remarkable results, not entirely to the use of augmenters, but also to the metal, "de Laval" type, nozzles developed by G. Aldred, which gave a thrust three times greater than that of a similar commercially obtained rocket charge. By the use of augmenters, this reactive force was further multiplied more than ten times, while the same type augmenter device, fitted to a commercial rocket of identical charge, merely gave a thrust increase of three.

It is of particular interest to note that firing runs of over 30 *minutes* were obtained by the group, using nine individual rocket units fired in sequence and operated on the same principle of feed as the automatic revolver. With this device, it was found quite possible to maintain a constant thrust of 450lb. at velocities up to 900ft./sec. The complete unit, fully charged with propellant, weighed less than 750lb., more than half this figure constituting fuel. The power ratio was thus a little under 1lb./h.p.

Another experimental device employing a nozzle with a jet discharge of 2lb./sec., is attributed to have developed fully 6,500 h.p. The jet velocity was given as 7,000ft./sec. With thrust augmenters, this gave a thrust of six tons at forward speeds up to 80 m.p.h. The complete propulsion unit, which weighed two tons, had an overall length of 40ft., with a maximum diameter of 20ft.

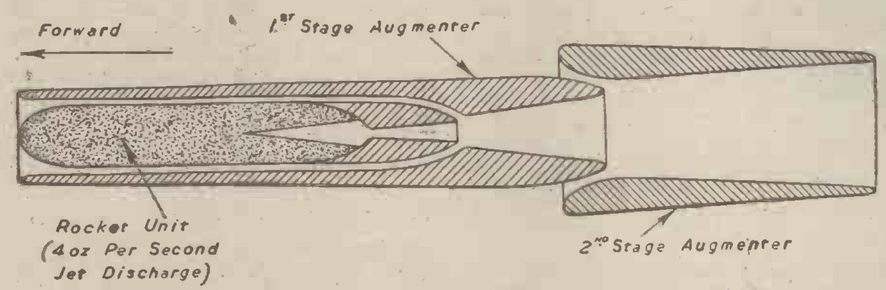


*Fig. 19.—Sectional view of powder charge rocket unit with 2-stage augmenters—developed in Scotland* (1936).

### Rockets in the Spanish Civil War

Mr. P. Blair—previously mentioned in connection with the Scottish research—working in Spain during the Civil War, took part in the development of several types of military rockets. The great majority of these were high explosive carriers, employing a liquid fuelled, constant volume, motor. As in the Scottish experiments, the rockets were fitted with thrust augmenters, and fired from a "starter tube." The launching apparatus, shown diagrammatically in Fig. 19, was a portable arrangement, and in order to absorb the thrust recoil in the starter tube the back end was not closed; instead a wood and cardboard cylinder, filled with water—which closely fitted the bore of the tube—was pushed into the rear. The backward pressure built up behind the rocket was taken by the block, which was ultimately blown out from the tube; the crew having previously taken cover at the sides.

The rocket projectile, shown in Fig. 20, employed paraffin as fuel, with liquid oxygen. It incorporated a one-stage augmenter, with a tail stabilising spinner. The initial weight of the projectile, fully charged with propellant, was approximately 48lb. At the time of impact, on target, this weight was reduced to 30lb., due principally to consumption of the fuel and oxygen, and also, because the augmenter and spinner were always torn away in flight by the pressure of the forced draught air flow. The projectile was ejected from the starter tube with a muzzle velocity of about 500 or 550ft./sec., and accelerated at between 2 and 3g. on a high trajectory.

### "Hot-spot" Ignition

The motors were fired by a development of "hot-spot" ignition, and, to facilitate starting, also pre-heated with oxy-acetylene flame jets.

A smaller version of the same type projectile, which weighed only 10lb., was fired from a 50 mm. starter tube. These rockets had an extremely accurate trajectory and were effective in a high percentage of hits at 3,000 yards. At this range, their impact velocity was over 2,000ft./sec.

These experiments with liquid fuelled war rockets proved clearly that by the proper use of the starter tube and thrust augmenters fully 80 per cent. of the fuel required in raising the speed from 0 to 2,000ft./sec. could be saved.

Apart from the high explosive rocket, the Spanish Civil War saw the employment of powder charge rockets, containing propaganda leaflets, which were fired over the opposing lines. Similarly, "leaflet rockets" were used during the Russo-Finnish conflict, and also by the Germans in the invasion of Denmark in 1940.

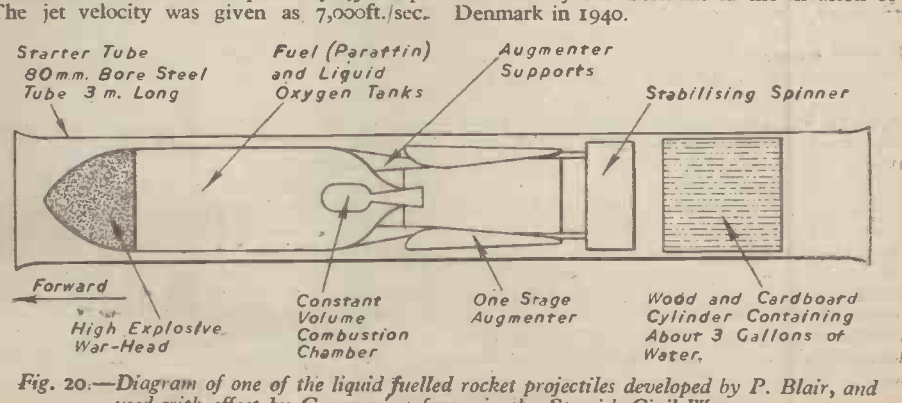


*Fig. 20.—Diagram of one of the liquid fuelled rocket projectiles developed by P. Blair, and used with effect by Government forces in the Spanish Civil War.*