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# PRACTICAL MECHANICS

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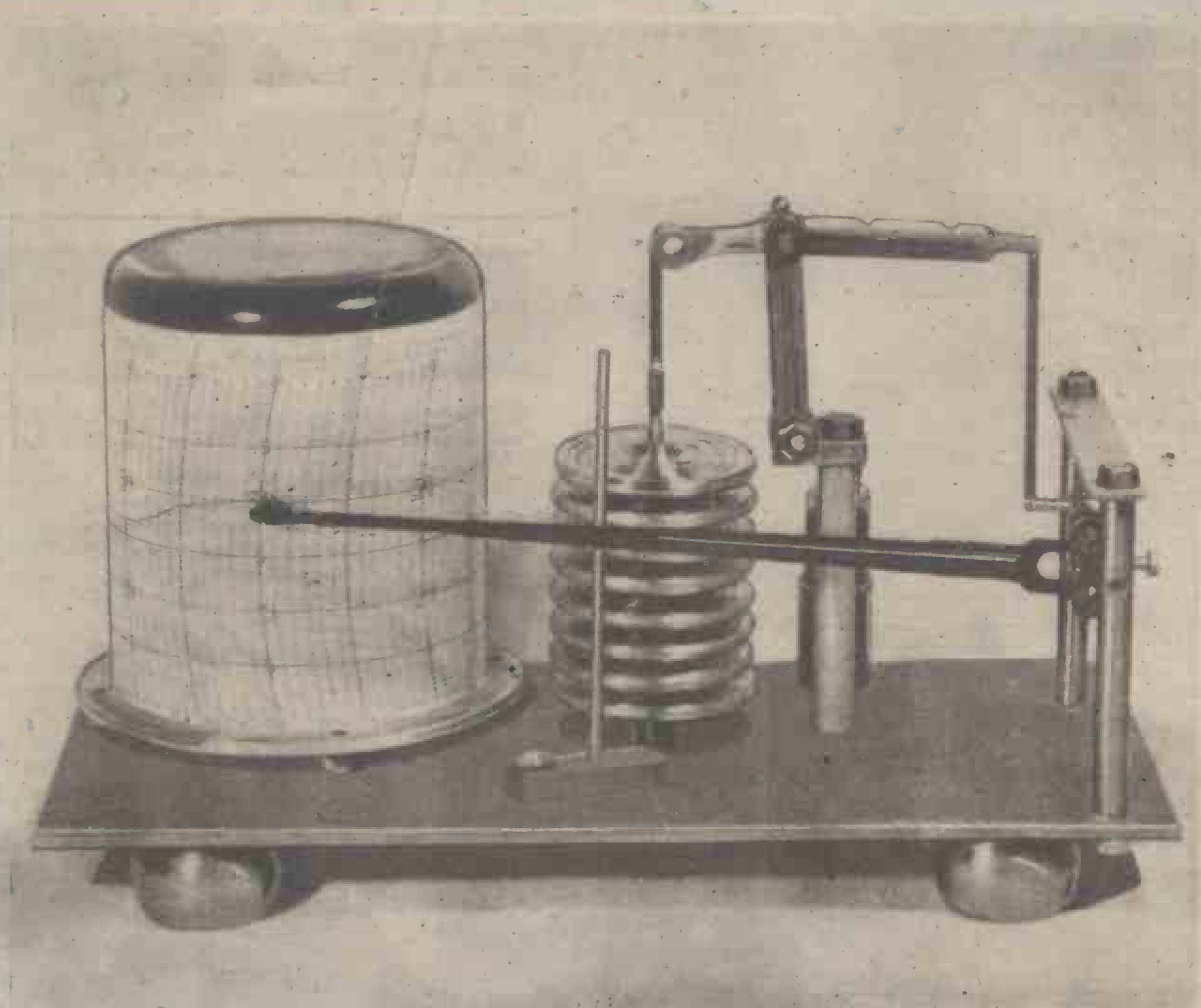

# Rocket Propulsion

## Further Details of U.S. Research : The American Rocket Society and its Affiliates : The United States Rocket Society

By K. W. GATLAND

HAVING covered the work of the American Rocket Society in fair detail; and before going on to review the research of the more recent contemporary U.S. groups, a word about the Society's present-day activities. As might be supposed, war conditions have largely forced the abandonment of any specific technical development programme, and many of the Society's members are engaged on research in the Government laboratories, helping along the rocket's development under the most satisfactory conditions of finance and labour.

Within the Society research is maintained to some extent by theoretical work, occasionally supplemented by small-scale experimentation. It will be readily appreciated that any more extensive practical work carried out by the Society, with its limited resources, would be rather insignificant at the present time, when war sponsored research into reaction propulsion systems is proceeding under conditions which promote large-scale and rapid technical development.

### Basis of Wartime Development

The Society's aim throughout its existence has been the encouragement of scientific research and the engineering development of reaction propulsor devices and their application to the problems of transportation and communication, and, in recent times, this has been extended to include the military application of rocket power.

That the American Rocket Society is the most widely renowned group of its kind is no over-statement. In many ways its research has formed the basis for the design of the military rockets which have proved so effective in the hands of the Allied land, air and sea-borne forces, and, in this regard, it should be remembered that while the American group and similar groups throughout the world were struggling along with their researches under most unfavourable conditions of finance, responsible Governments remained apathetic to talk of rockets and reaction flight in general. It is well that so much experimentation had been privately conducted in pre-war years. Had this not been the case the Nazi authorities, quick to realise the rocket's vast possibilities in the work of the free-German Verin für Raumschiffahrt E.V., and whose experiments were commenced years before the outbreak of the war, might well have made the position of the German military forces a far less precarious one.

### Affiliate Groups—

There are three rocket groups affiliated to the American Rocket Society, although much of their research is carried out independent of the parent body. Of these, the New York, Westchester Rocket Society, is the most long established, having its foundation in 1936.

In the years prior to its affiliation the group conducted a theoretical study of alighting methods, other than the parachute, suitable for adaption to the rocket projectile. Of the types investigated the gyro-plane type rotor was considered worthy of investigation.

A start was made with the construction of a 10ft. diameter rotor, and other sizes of

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varying design were subsequently built and tested in free-flight. These experiments made it clear that the available data concerning the design and theory of the gyro-plane rotor were inadequate for rocket use, and, in consequence, further tests were carried out with the object of determining the effect of dihedral and attack angle changes, as well as wing loading of rotor blades during vertical ascent.

In a report to the American Rocket Society, N. Limber, writer and prominent member of the Westchester Society, has pointed out that when considering efficiency and desirability, the rotor, when compared with the parachute, is somewhat inferior both as regards weight and compactness. In conducting further tests, Mr. Limber says that it is hoped to prove or disprove certain apparent advantages the rotor system may offer, principally decrease in drift, and greater dependability.

### Water Cooled Rocket Unit

The group has also designed several liquid-fueled rocket motors. One of these propulsion units, which has reached the construction stage, embodies a 1in. nozzle constriction, and is one of the largest of its type yet produced by the rocket groups.

The unit, which is built of monel, brass and dural, features a special system permitting the attachment of various liquid oxygen feeding ports. The combustion feed, too, is somewhat unique in that the propellant is first allowed to expand in a mixing chamber, prior to entry into the combustion chamber. Cooling is arranged through the feeding of water from a radial slot, which results in the formation of a protective layer of superheated steam around the inner wall of the firing chamber adjacent to the nozzle "throat."

The Society's more recent investigations have concerned supersonic flow and its effect on the flight efficiency of projectiles.

### California Rocket Society

The initial experiments of the affiliate California Rocket Society, like the majority of tests previously described, concerned the powder rocket, its stability and the methods of parachute release. These further trials took place in May, 1941, and again, the powder cartridges were obtained commercially.

A simple beam balance, built by members of the group, served to gain for the experimenters some knowledge of the thrust values of the charges, and this consisted simply of a steel bar, pivoted off-centre, and calibrated by applying various known weights along the free end. During testing, a stop watch was placed close to the thrust indicator and a ciné camera focused on the two instruments.

The initial series of ground trials concerned the standard commercial 8lb. charge with 11/16in. diameter fireclay nozzle, and a first firing recorded a thrust duration of 1.5 seconds. Unfortunately, a fault in the sighting of the camera left the thrust figure uncharted. A second test was made with a rocket charge to which had been fitted a specially constructed steel nozzle having a length of 2.50in. and a "throat" diameter of 9/16in. When fired, the charge exploded the case after only 0.1 second burning, due, obviously, to the reduced nozzle orifice.

A ½in. diameter fireclay nozzle, 2in. in length, featured in the third experiment, but this burned out almost immediately after ignition. A final test was made with an unmodified charge weighing 25oz., of which 12oz. constituted black powder. This fired for an effective period of 2.0 seconds and the scale showed a thrust of 27lb. at maximum combustion. It burned for a further 8 seconds at zero thrust.

### Free-flight Research

A month later, experimentation was carried out with powder rockets in free-flight. Each of these was fitted with a parachute, which was packed into a compartment at the nose; the nosing being placed lightly on top. The release action, in this instance, depended upon the "spring" of the parachute's own compression, which acted to throw off the nose cap when the rocket was slowed up at the flight apex.

Several firings were made to test the efficiency of this release method, and quite satisfactory results were achieved; the parachute being ejected at the peak trajectory in almost every instance.

The group later carried out experiments with powder rockets each fitted with a small gyroscope, but due to the very limited burning time of the propulsion charges, the flight results were largely inconclusive.

### Conclusion

The firing duration of the 8lb. commercial charge was obviously not adequate for the majority of flight tests. It was further proved inadvisable to modify the standard charge either by the removal of part of the casing, or through the constriction of the nozzle orifice beyond the designed diameter.

### Fluid-solid Fueled Rocket Motor

Unlike the majority of U.S. groups, the California Rocket Society has maintained its technical development programme throughout the war period, and research in the 1943 period concerned the constant-volume rocket motor. Outstanding in this work are several motor developments of a type which employ a liquid-solid propellant, and tests have already shown promise of very high efficiencies in the fully developed version. It is unfortunate that essential details, both as regards design and test results of these units have not been made available for publication.

The Yale Rocket Club is the more recent affiliate group, and its work to date has largely comprised the building and free-flight tests of powder rockets.

### The G.A.L.C.I.T. Rocket Research Society

The Guggenheim Aeronautical Laboratory of the California Institute of Technology has established a special section for the development of rocket propulsor systems. In fact, the group's inception dates back to 1936; those chiefly responsible being F. J. Malina and J. Parsons, of the Halifax Powder Company.

During the year of inauguration little of a practical nature was carried out, most of the early work being centred toward gaining a thorough understanding of the subject from the development of known principles and propulsion methods in the light of the more current test results; these, principally due to the American Rocket Society.

In more recent years tests have been conducted of several constant-volume liquid-fueled motors, and also a powder motor, powered by successive impulse.

For the test of such units the group has constructed three proving stands; and the most ambitious of these is shown diagrammatically in Fig. 29. The measurement of thrust reaction in this particular arrangement is achieved through the use of a development of the torsion balance, using heavy feed lines as the torsion member. A lever made up of these tubes supports the motor under test and also extends forward of the torsion member, being balanced by a beam and counterweight. A dial gauge, functioned by an extension on the beam balance, is operated when the thrust of the motor causes rotation about the torsion member.

This system of recording has resulted in the attainment of exceptionally high accuracies; the instruments fitted to the apparatus recording, in addition to the developed thrust, such data as the combustion chamber pressure; propellant feed-line and cylinder pressures; rate of flow of combustibles, and the test duration. The gauges are, of course, ciné photographed throughout the testing period, thereby enabling later study of the results.

### Carbon Built, Liquid-fuel Motor

One of the most novel types of several constant-volume rocket motors produced by the G.A.L.C.I.T. is shown in Fig. 30. It is, of course, a liquid propellant motor, and is notable in that all combustion faces are of carbon. In this particular instance, the combustion chamber and nozzle were machined from carbon electrode, and the motor encased tightly within a steel jacket, to which the combustion loads were transmitted. This consisting simply of a cylindrical liner with plates bolted down firmly at each end.

On test the motor recorded a chamber pressure of 300lb./sq. in. for a period of one minute, and a subsequent examination showed that the nozzle "throat," which originally had a diameter of .136in., suffered only an enlargement of .015in. under the erosion of the exhaust efflux.

### Successive Loading Powder Motor

A particularly interesting series of experiments, aimed at the development of a powder rocket motor of the constant-volume type, were conducted by J. W. Parsons, of the G.A.L.C.I.T. Rocket Research Society, and E. S. Forman; the work covering a period of years.

In work of this nature there are, of course, two distinct systems to consider; the slow-burning powder as applied in pyrotechnics, etc., and the rapid burning type demonstrated by Prof. R. H. Goddard. The latter has shown promise of higher efficiencies, and used in conjunction with a suitable motor and feeding arrangement, it would provide a well controlled and even rate of combustion with a thrust duration effective for periods comparable with the liquid propellant rockets.

The development of an efficient mechanism for the successive injection and firing of small charges is, of course, the principal factor, and many problems are attendant in the design of such apparatus. There must, of necessity, be provided access in the combustion chamber for the entry of the powder charges, and during the individual firings this must be closed, with a gas tight seal. When it is considered that the injecting and sealing action must invariably take place several times a *second*, the design difficulties can be well appreciated.

The function of this type motor is more in the nature of rapid, individual explosions than a continuous expansion as associated with the more conventional liquid fuel rocket engine. This means that while the heat energy of the powder used is relatively low, the comburant gases are ejected at a considerable velocity, thereby permitting high thermal efficiencies.

### Goddard Research

Although Goddard is reputed to have developed an automatic powder motor reloaded by thrust recoil, no performance data has been made available. In the absence of this information, the results of his initial experiments with individual charges are fair indication of the efficiencies attainable. Using a commercial "pistol" powder classified "Infalilble" (9.0259 gm. mass) as a single charge

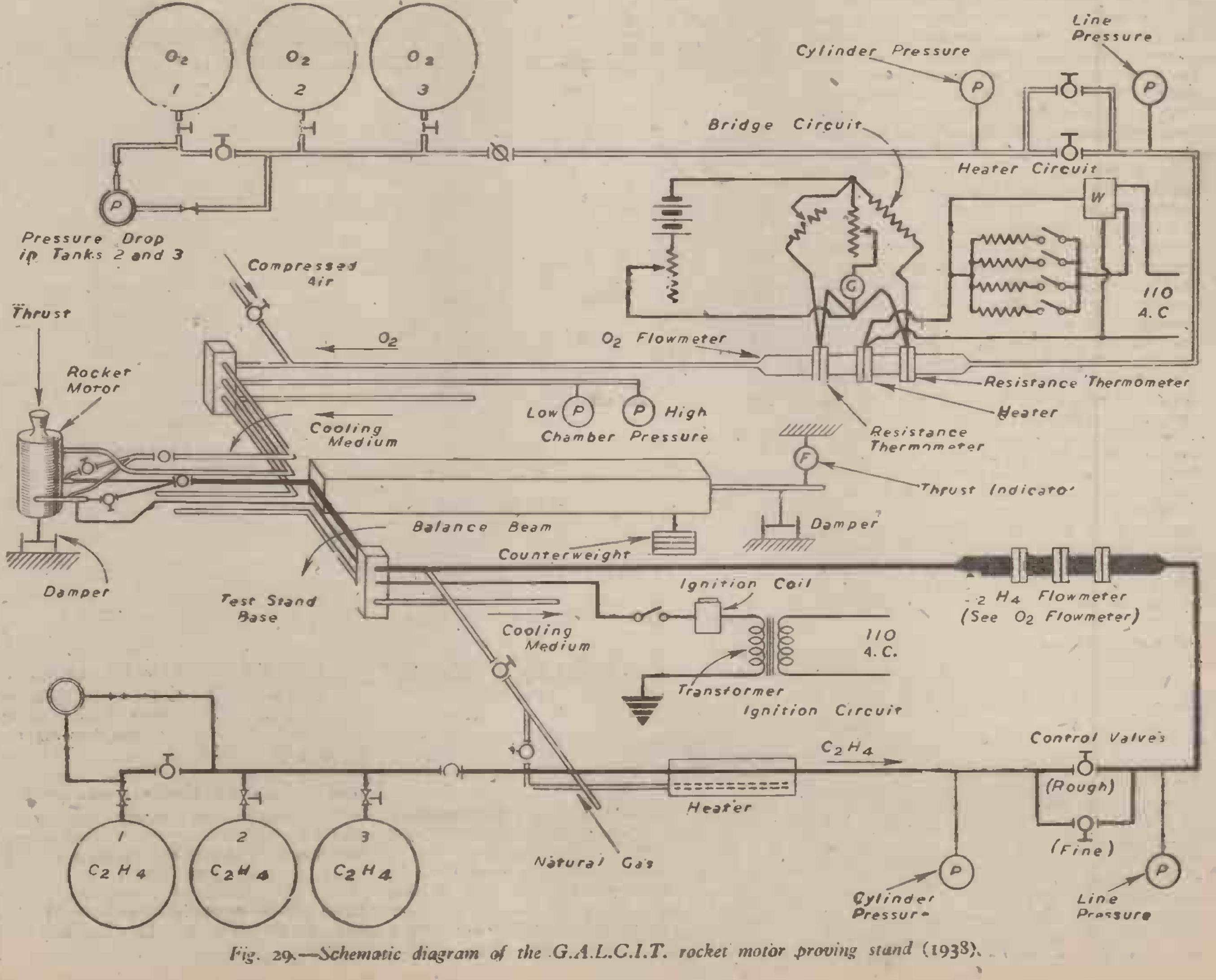


*Fig. 29.—Schematic diagram of the G.A.L.C.I.T. rocket motor proving stand (1938).*

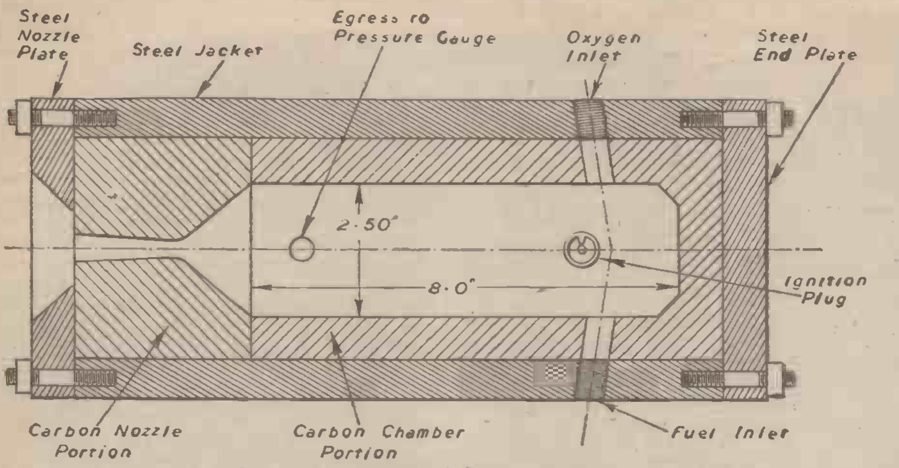


*Fig. 30.—Constant-volume rocket motor with firing faces of carbon, produced by the G.A.L.C.I.T. Rocket Research Group, California, U.S.A.*

compressed into a small experimental combustion chamber (length of chamber, 2.28 cms.; internal diameter, 2.6 cms.; length of nozzle, 16.29 cms.—de Laval type), proving tests recorded an exhaust velocity of 7,987 ft./sec., and an efficiency of 57.25 per cent.

The above figures illustrate the most satisfactory case arising from the use of a well-designed firing chamber, and incorporating an efficient nozzle which permitted optimum expansion of the comburant gases.

### More Recent Experiments

The Parsons-Forman preliminary experiments dealt with two single-charge combustion chambers (Fig. 31). These were made in order to gain data of the following all-important factors—(a) The effective exhaust velocity and thermal efficiency of the powder charge rocket obtainable with various powders. (b) The effect of chamber pressure on the thermal efficiency. (c) Methods of varying the chamber pressure. (d) Chamber and nozzle design, and (e) The effect of various methods of ignition and the physical state of the powder.

The original single charge motor, constructed of chrome-molybdenum steel, comprised simply a tube of heavy gauge having a nozzle at one end, and a screwed block at the other. It had a combustion chamber of ½in. diameter and two interchangeable nozzles of 3/16in. and ⅛in. diameter "throat" respectively, with a 6 deg. flare angle.

The second motor was similar, though somewhat larger and of increased strength. It had a machined combustion chamber of 1in. diameter, and a nozzle of ¼in. diameter orifice having a flare of 9½ deg. A Ludlum Seminole steel, treated to withstand a tensile stress of 130,000lb./sq. in., was used throughout.

In the first type, the powder, after its compression in the chamber, was fired by a simple touch fuse, while in the latter model, ignition was performed electrically, and a wad fitted in the "throat" orifice to improve the combustion pressure.

### Test Findings

A commercial black powder (Hercules-Laflin and Rand FFG), having a theoretical velocity of 7,900ft./sec. and nitro-cellulose powder (Hercules "Bullseye" smokeless powder), with a theoretical velocity of 10,600 ft./sec. featured in the testing.

Using these propellants, an exacting series of firings showed that the efficiencies of the test motors compared most favourably with the Goddard single-charge chambers. It was found, too, that an increased jet velocity, and efficiency, resulted from a decreased nozzle diameter, by an increased powder weight, and through the provision of wadding fitted at the nozzle "throat."

These factors, it will be noted, are those which tend to increase the chamber pressure.

After repeated firing, using the large chamber, a serious erosion of the nozzle "throat" became apparent, and this resulted in a marked decline of efficiency, and, as might be supposed, considerable fouling was caused by the black powder, which was entirely absent in the use of the smokeless variety.

With a well-designed motor, and using a pure fuel compound (nitro-cellulose), ash produced in combustion should only be condensed after the effluent had been ejected from the nozzle.

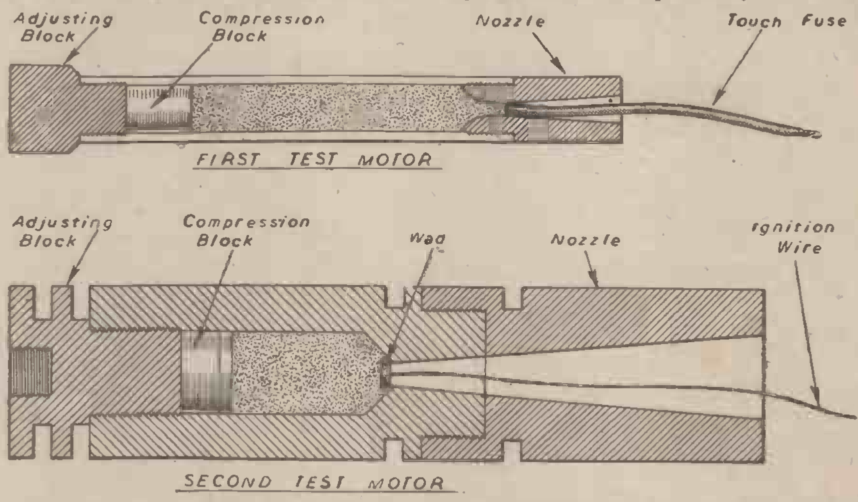


*Fig. 31.—Sectional diagram showing the two experimental firing chambers built for the test of "shot" powders (Parsons and Forman, California, U.S.A., 1938).*

It is of interest to note that there was no serious heating at any time during the experiments; the motors being only slightly warm to the hand after successive firing. This is accounted to the high speed of gas ejection in that the individual charges did not remain in the chamber for a sufficient period to create high temperatures. The small-grained, rapid-burning smokeless powders are more completely combusted and produce a swifter release of pressure. The duration of combustion, under the prevailing test conditions of smokeless powder, is estimated to lie between 1/5,000 sec. to 1/10,000 sec., which permits kinectic conversion to take place with the minimum heat loss.

More recent work has involved the construction of an automatic injection mechanism, and in addition to providing stand tests, it is hoped to employ this motor for flight research. Participating in this development, the efforts of F. J. Malina and H. S. Taien (both of the G.A.L.C.I.T. Rocket Research Society), Mr. Spade, of the Ludlum Steel Co., and Mr. H. N. Marsh, of the Hercules Powder Co., should not go without mention.

### The United States Rocket Society

Although having its formation as recent as 1942, the United States Rocket Society is fast becoming a prominent astronautical body, despite the fact that its present function is purely academic. The group's principal aim during the war years has been the building up of a substantial membership, and this is largely composed of technicians, both of American industry and the armed forces.

Because of war conditions, it has, quite naturally, been found impossible to direct any programme of specific technical development, and in the interim period before practical experimentation is a possibility the coalition of information and data, the formation of discussion groups, and lecturing, comprises its principal wartime activities.

The founder, Mr. R. L. Farnsworth, has written as a first official work of the Society a review and bibliography, "Rockets—New Trail to Empire." This is a useful reference to the numerous U.S. technical literatures of rocket propulsion, and has undoubtedly done much in the way of publicity for the group.