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THE MECHANICS OF METEOROLOGY

NEWNES

# PRACTICAL MECHANICS

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EDITOR: F. J. CAMM

DECEMBER 1945

# Rocket Propulsion

## Rocket Propelled Aircraft; Research with Models

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*(Continued from page 51, November issue)*

*Three-quarter front view of the M.A.A. flying scale-model rocket aircraft. Note the radial air intake cowling over the rocket jets.*

THE outbreak of hostilities, too, had much effect on the activities of the other British groups—the Manchester Astronautical Association and the Astronautical Development Society (the latter was not given a title until 1941, being originally a small local group)—and although it did not cause their disbandment, there was an immediate curtailment of active research under the Defence Regulations Act, 1939, which made the preparation and firing of rockets during the war illegal.

Thereafter theoretical research became the vogue, and much valuable work has been conducted during the war years of which detailed reports have been published on the following subjects: (a) The fundamental design of rocket aircraft; (b) The design development of meteorological sounding rockets; and (c) An investigation of reloading systems in "solid" fueled rocket units.

### Rocket Aircraft

In the first issue of the Manchester Association's Journal, (*Spacewards*, Vol. 1, No. 1, August, 1939), were published the initial sketches of a single-seat rocket aircraft, suggested by the M.A.A. Research Committee (Fig. 41). This conception was intended merely to form the basis for a report of the engineering and aerodynamical problems involved in the development of high speed, high altitude aircraft, and as such the actual design was not pursued in detail. It was, however, necessary to carry out a preliminary design procedure in order to estimate the essential dimensions and weights for the purpose of approximating the performance.

The machine in question (Fig. 41) differed in many ways from the orthodox. A high-wing aircraft, its fuselage was short and stubby, with horizontal surfaces swept back well beyond the rear. The vertical stabiliser, fin and rudder emanated from just aft of the nose cabin and, similarly, swept beyond the fuselage, while the main-plane—of low aspect ratio, two-third ellipse plan-form—was positioned almost centrally along it.

Instead of the conventional landing wheel arrangement, a double skid alighting gear was attached beneath the fuselage.

A small pressure control cabin was situated at the nose, and in the space immediately below, two small tanks, one oxygen, the other alcohol—intended to feed a small rocket motor firing forward and downward—were fitted. This unit was provided for flight manœuvring and landing.

A battery of propellant tanks occupied the space behind the cabin, and at the extreme rear was fitted the rocket propulsor.

### The Propulsion Unit

The driving motor was something quite new in rocket units, and solved the propellant feed problem very simply. Instead of employing a gas charging system, or pressure pumps, which would necessitate an auxiliary driving motor, a fuel injector system was devised in which the oxygen and fuel were centrifugally fed to a multi-chamber propulsor under the axial rotation of the complete unit. The centrifugal injector is shown in Fig. 42. It is an example of an entirely self-feed arrangement

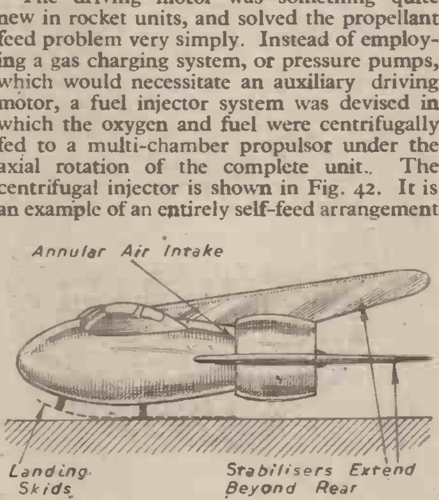


*Fig. 41.—Suggested scheme for an air-augmented rocket aircraft. Air is injected over exhaust jets and expanded to increase the mass effluent.—M. A. A. (1940).*

and apart from the initial priming of propellant, the unit is completely automatic in operation, requiring no additional power services.

With reference to the figure, the rotary portion of the injector consists essentially of the centrifugal feed unit, and a number of reaction chambers, which are axially offset, and equally spaced around it. The system is designed to function as follows: A few seconds continuous supply of fuel and oxygen are initially primed to the reaction chambers by means of auxiliary pressure chargers. These are housed within the conical tail fairing. The ignition circuit is then closed and the rocket chambers fired, causing the unit to rotate due to the offset thrust. This immediately affects pressurisation of the fuel tanks through the rotation of the oxygen feed shaft, and the pump geared from it; at the same time the oxygen feed valve is automatically released, permitting the fuel and oxygen to pass to the centrifugal unit where delivery is made to the reaction chambers in correctly metered proportion, and at constant and high pressure.

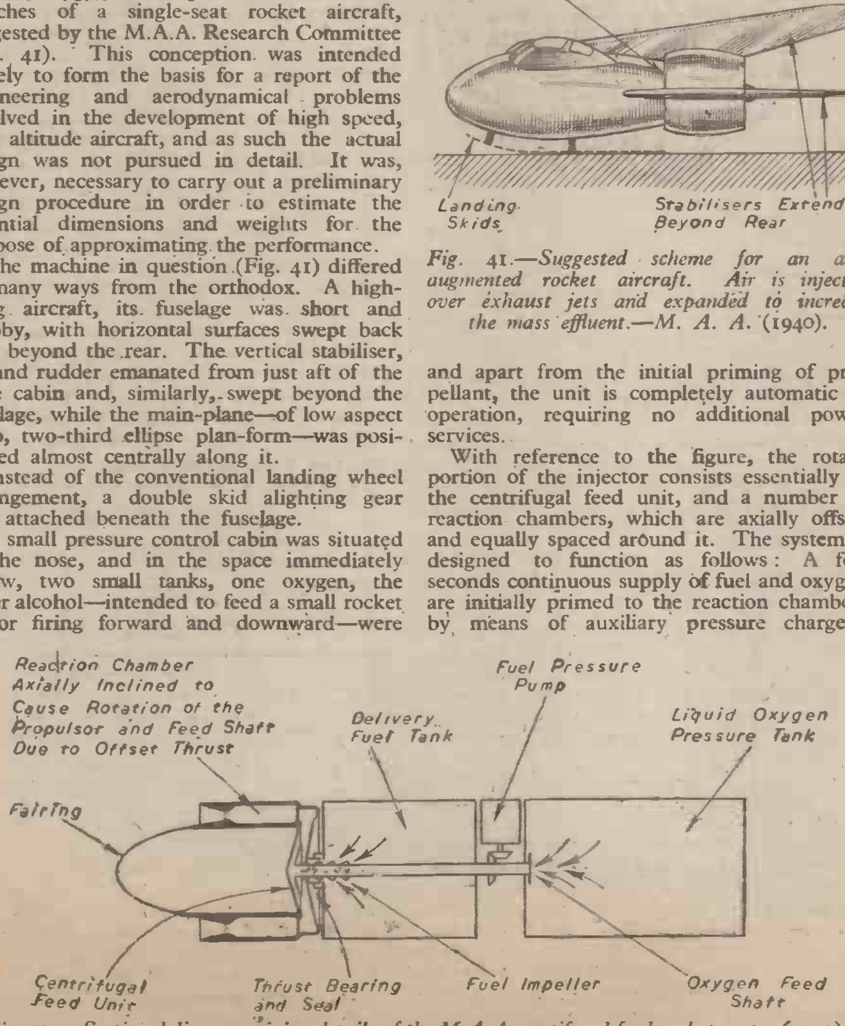


*Fig. 42.—Sectional diagram giving details of the M.A.A. centifugal feed rocket-motor* (1940).

### Model Research

Several models of the aircraft were constructed, mainly for the purpose of gaining some idea of its stability, but, unfortunately, only the initial flight trials of a first powder driven model were possible owing to its completion only a few weeks before the outbreak of hostilities.

At that time plans had been formulated for the construction of a large oxy-alcohol powered model, but the war left this particular project unstarted.

A later model was fitted with a thrust augmenter located behind the centre of gravity and the centre of thrust, attached over the propelling jets. Gliding trials, however, proved this arrangement unsatisfactory in that it had a detrimental effect on stability. Although the augmenter maintained the model on a direct course during sustained flight, this ideal condition remained even when the machine nosed downward for landing, when such a condition became by no means ideal as the 'plane was incapable of levelling out. The obvious remedy was to provide the intake for the augmenter forward of the centre of gravity and thrust, and modifications were made to the basic design to provide for this.

Shortly after the cessation of hostilities in Europe, the improved model was flown under power, and showed itself capable of rapid and well stabilised flight.

The propulsion unit in the models comprised, in each instance, eight individual powder charges. Four of these were termed "primary" and the remainder "secondary," being alternately placed on a circle in order to balance the thrust, and slightly inclined to impart axial rotation.

The primary charges are, of course, provided for the initial acceleration, and the secondaries for maintaining level flight once the requisite height has been attained. To achieve this, the primary units were provided with a more energetic powder composition than the secondaries, each firing phase being a duration of four seconds.

Complete references to the calculations arrived at of the machine's performance are

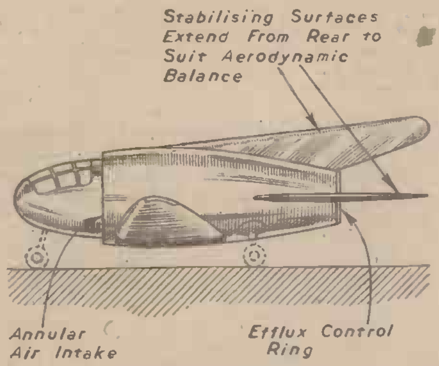


*Fig.* 43.—*Suggested layout for an air-augmented rocket aircraft. Air is inducted and expanded by the exhaust stream in a secondary "expansion chamber."—A. D. S.* (1941).

given in the journal, *Spacewards*, January to October, 1940, Vol. 1, Nos. 2, 3 and 4, Vol. 2, No. 1.

### The Astronautical Development Society

This is a convenient stage to introduce the work of the Astronautical Development Society, as its early researches were very much akin to those of the Manchester group.

The A.D.S., formed in July, 1941, by the writer and Mr. H. N. Pantlin, around the nucleus of a small local group at Surbiton, Surrey—whose activities date back to the summer 1938—was originally an independent organisation.

In January, 1942, however, contact was established with the M.A.A., and within a short while, in August of the same year, the two societies were provisionally amalgamated. This resulted in an agreement to the effect that, in order to facilitate a more "localised" programme of research for each group, the M.A.A. should govern the rocket interest of northern England and Wales and Scotland, while the A.D.S. administered to the southern counties.

The membership total of the Manchester group at that time was the very low figure of 13, while that of the A.D.S. was little better at 25. The war brought about a severe reduction in members, and both groups had definitely seen better days. The increased strength arising from the merger, however, had almost immediate effect and, by 1943, the total membership was over 100. That year, too, saw the issue of a combined journal and bulletin; the title of the former remaining *Spacewards*.

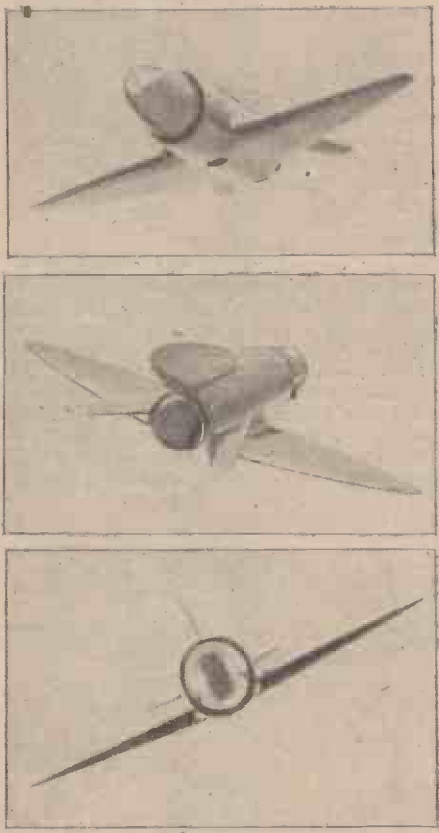
Although the pre-A.D.S. local group carried out free-flight tests of small powder rocket units, these were, in essence, very similar to those conducted by the Manchester groups, and were very largely pure duplication.

The first really significant work of the society proper was the investigation of problems associated with the development of rocket aircraft, and this survey was commenced in complete ignorance of the very similar research which was being pursued, at the same time, in Manchester. When notes were compared later, it was found that almost identical principles had been evolved by the two independently working groups.

The M.A.A. concluded its rocket 'plane investigations shortly after the amalgamation, to commence a mathematical survey of sounding rocket trajectories, leaving the A.D.S. to continue the original line of work.

Unlike the M.A.A. rocket 'plane conception, the A.D.S. model (Fig. 43) had a low wing and an augmenter intake placed near the nose. Its only outward similarity was the tail assembly, which comprised two horizontal stabilisers, and a single dorsal fin, swept back beyond the rear fuselage. These surfaces were intended purely as *stabilisers*, and as such they were not fitted with control aerofoils. Instead, directional control was effected by the simple procedure of providing an efflux discharge ring within the nozzle mouth, free to swivel—at the control of the pilot—in any direction, up, down, or sideways, so that the exhaust impinged, thereby causing offset thrust and controlling the 'plane's flight with the same effect as rudder and elevators. The wing was fitted with ailerons in the usual way.

The cabin formed the nose of the aircraft, and a large clear-view Perspex type hood was fitted in keeping with the nose contour, intended to afford a wide angle field of vision.



*Three views of the original air-augmented rocket 'plane model developed by the A. D. S., and built by a member of the society, Mr. D. Ashton. Photographs by Mr. H. J. Kendrick, Surbiton.*

The propellant tanks were well dispersed about the centre of gravity; the main fuel tank being immediately behind the cabin, while two additional containers were placed just outboard of the wing roots. A large cylindrical liquid oxygen tank extended from the nose fuel tank to the motor at the rear end of the fuselage.

### A Turbo-thrust-feed Motor

The liquid fuel motor provisionally developed for the original A.D.S. model was, too, somewhat unique in design, and as with the M.A.A. "centrifugal injector," the propellant feed problem was solved quite simply. Similarly, once set in function, the unit would operate continuously at a constant feed pressure until the propellant was exhausted.

The feed system in the A.D.S. motor (Fig. 44) was arranged through a turbine driven pump, the turbine being fitted directly inside the combustion chamber at the back, and functioned by the thrust pressure of the expanding gases. A hollow shaft, fitted through the axis of the turbine, passed out through the rear wall of the chamber, and from this was geared the oxygen and fuel pumps.

The end of the shaft fitted into the oxygen delivery tank, in which it rotated on a sealed bearing, allowing the oxygen to pass through the shaft to the combustion chamber. The oxygen pump served to pressurise the liquid oxygen tank, and thus it was ensured that the oxygen entered for combustion at a high and uniform pressure.

The fuel—similarly forced from its tanks under pressure from the pump—prior to entering the chamber was utilised in cooling the nozzle. After passing through the jacketed portion, having been conveniently vaporised by the absorbed heat, it was fed for combustion, entering from two inlets placed behind the turbine.

On the reverse side of the turbine was fitted a centrifugal impeller blade system intended to fling the fuel out into the chamber from the back of the turbine vanes, and in this way the oxygen issuing from the shaft was isolated from the chamber walls until the propellant was adequately mixed. Thus, the danger of oxidation, the main cause of earlier motors' disruption, was thought to be largely eliminated.

A multi-chamber liquid-fuel motor—designed on the same principle as the M.A.A. "centrifugal injector"—was later proceeded with and in this it was arranged to feed the propellant centrifugally through rotating the complete unit by offset thrust. In view of the large masses involved, however, and the likelihood of excessive torque, a model of the unit was not constructed, although a model aircraft employing a similar powder system was successfully flown, prior to the official formation of the society.

### Rocket Aircraft Development

The conclusions derived from the M.A.A. and A.D.S. investigations, covering the

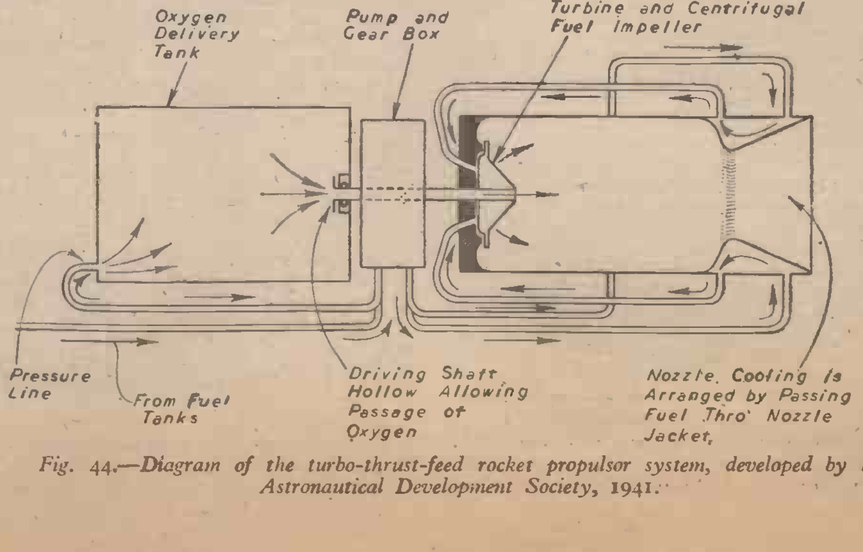


*Fig.* 44.—*Diagram of the turbo-thrust-feed rocket propulsor system, developed by the Astronautical Development Society*, 1941.

essential disadvantages and advantages of the rocket system applied to aircraft, may be jointly summed up as follows: For reason of a limited duration of power, due to the heavy rate of propellant consumption, the aircraft powered by what we may term "chemical rocket propulsion," is not likely to realise commercial application. Against this, however, there is the implication of *controlled* atomic power.

The "uranium bomb" has given dramatic illustration of the vast powers available in atomic disruption, and clearly, once this energy can be harnessed for direct *reaction*, we will have at our disposal a highly powerful and economic propulsor agent, not only adequate for all terrestrial uses, but also capable of fuelling the most enterprising "interplanetary space-vessel."

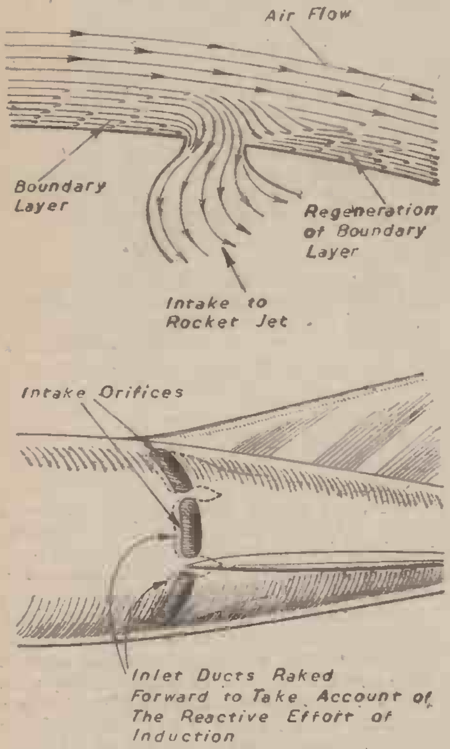


*Fig. 45.—Diagrammatic view and section showing abstraction of boundary layer.*

Many technical difficulties remain, however, before the liberation of this energy can be moderated; and there are also several associated problems which will invariably arise in its application—principally, the very high temperatures and pressures that are likely to be raised in an "atomic generator," and the necessity for providing suitable screening against the harmful radiation emitted in the bombardment of the radio-active U-235 isotope.

This subject is too vast in its possibilities to pass over hurriedly, and a more detailed account will be given in a later article.

**The Thrust-augmenter**

Apart from the high fuel consumption in chemical rocket units, the second disadvantage, directly associated with the first, is their inability to function without profuse waste of energy at low speeds, and within the atmosphere. Hence the importance given to the *thrust-augmenter*, which aims to increase the mass flow while decreasing the speed of ejection. The need for providing entry for the augmenter forward of the C.G. and C.T. has already been mentioned, but it is obvious that this involves a large area of ducting, which naturally would add materially to the drag due to friction. The better solution would appear to be the use of inlets flush to the skin, and, in this form, stability would not be impaired even though they were located in the rear fuselage. Not only would this arrangement solve the intake problem, but it would also bring about a useful increase of the form efficiency due to the removal of *boundary layer.*

**Boundary Layer Control**

The total drag of an aircraft is made up in two components: (a) skin friction, and (b) the formation of a turbulent wake. The form of the aircraft, of course, determines the character of pressure distribution about its surface, and, with careful streamlining, these changes in pressure can be arranged to take place gradually, so that the transition of laminar flow into turbulence is close to the rear of the body, and results in a narrow wake. Under such conditions the resistance due to turbulence composes only a very small part of the total drag, the remainder being due to surface friction; the boundary layer, which has effect over almost the entire surface.

The boundary layer is formed as the result of frictional forces which arise between the surface and the air, represented by the resistance which each particle offers as it moves past others. The air particles immediately adjacent to the surface adhere, while those of subsequent layers, less able to resist the air flow, progressively obtain the speed of free air, the degree of frictional retard diminishing as the distance from the surface increases. This results in the formation of a thin layer of vortices over the surface, which, at the point of transition, suddenly effects a change, and the air particles in the boundary layer assume a vigorous swirling at right angles to the direction of flow, causing the turbulent wake.

The location of the intake is, therefore, most effective just forward of the point of transition, so that the depth increment of the boundary layer is reduced and the separation into turbulence delayed. Investigations have shown the most efficient intake arrangement for this purpose to be simple, wide slots, set at right angles to the skin contour, and flush in the surface, as shown in Fig. 45. The diagram gives some idea of the boundary layer formation in this region, and indicates the method of abstraction to the rocket propulsor.

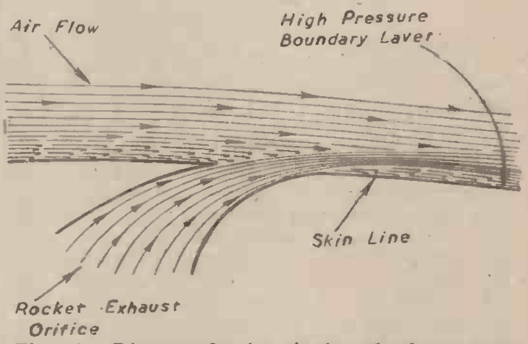


*Fig. 46.—Diagram showing ejection of exhaust on to skin surface. This action accelerates the boundary layer and delays separation of flow.*

It is also a possibility to discharge the combustion effluent on to the outer surface in order to speed the boundary layer as a further means of delaying the separation. In this instance, the expulsion orifice is most efficiently arranged with its leading edge fined sharply to blend with the skin line, so that the gases are ejected tangentially to the skin curvature (Fig. 46).

These methods of controlling the boundary layer are, of course, most beneficial when applied in thermal-jet, and air-augmented rocket systems, because of the large volume of air to be exercised in the propulsors, and the large mass flow available in ejection.

*(To be continued)*

## From Bombers to Furniture

*Another British factory is switching over to peacetime production. In the illustration workmen in the background are assembling parts of a Mosquito fighter-bomber, while others in the foreground are making utility furniture in one of the assembling bays of the Walthamstow factory of F. Wrighton and Sons.*