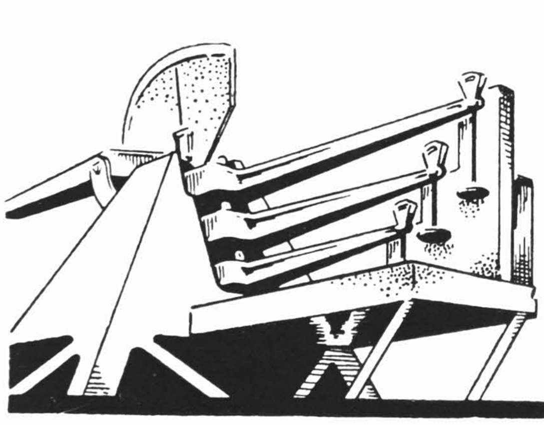
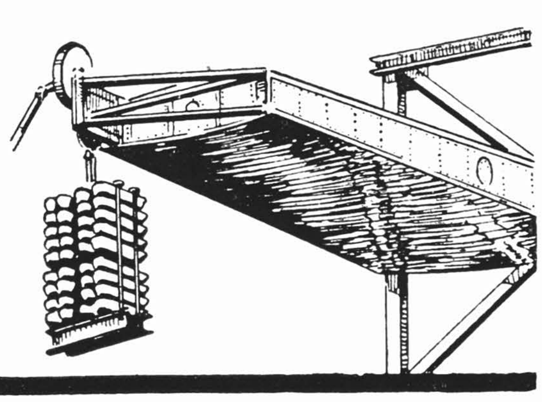


Aircraft Engineering

THE MONTHLY SCIENTIFIC AND TECHNICAL ORGAN
OF THE AERONAUTICAL ENGINEERING PROFESSION



VOL XXIII No 270 AUGUST 1951

The Substance of a Dream

ONCE more we are indebted to the Institution of Mechanical Engineers for giving us permission to reproduce a contribution to its Transactions. In the last few years the Institution has benefited engineers by making available a number of quite outstanding papers on aeronautical and allied subjects and has always been most courteous and obliging in giving us facilities for publishing in Aircraft Engineering such of them as we have wished to reproduce.

A Considered Policy

As regular readers will be aware, we have always felt it to be one of our most useful functions to bring to the notice of members of the aeronautical engineering profession papers read before learned societies, or published in various foreign periodicals, which they might not otherwise see, or, if unfamiliar with the language concerned, understand except in translation form. It will perhaps be remembered that during the 1939-1945 war period we made special efforts to keep our eyes open for important articles published abroad—particularly in Germany—and have them translated so that readers could benefit from the information contained in them. Of course, quite a considerable proportion of our home readers are themselves members of 'the Mechanicals' but there are many, particularly students and younger subscribers who are not, and would therefore be likely to miss these papers. In any case, those overseas are, we know, glad to have them brought to their notice. The reproduction of them here is, therefore, hardly more than a technical breach of our regular rule to publish in these columns only articles which are, in journalistic jargon, known as 'exclusive'.

Looking Backwards

The particular subject of Mr Thompson's paper is one that has had a romantic popular appeal ever since, to those who know their aeronautical literature, the appearance of seventeenth century imaginative publications, *The Man in the Moone: Or a Discourse of a Voyage thither* by Francis Godwin, Bishop of Hereford, and *The Discovery of a New World, or, a Discourse tending to prove that ('tis probable) there may be another Habitable World in the Moon. With a Discourse concerning the possibility of a Passage thither,* by (strangely enough) another bishop, John Wilkins, a famous Bishop of Chester. Both of these well-known, but now unfortunately scarcely obtainable, curiosities of aeronautical history are, incidentally, treasured items in the editorial collection of such books, while, for those who feel moved, by having their attention called to them now, to delve into them, they are available in the library of the Royal Aeronautical Society and, we believe, the archives of the Institution of the Aeronautical Sciences.

The above digression is not wholly irrelevant because there is no doubt that recent developments in rocket motors have led certain enthusiasts for the art of 'space travel' to allow their imagination to run considerably riot and hold out to the less-informed public prospects of expeditions to various planets which are unlikely (to say the least) to materialize in the immediately foreseeable future.

Opening the Window

The cold logical approach to the matter adopted by Mr Thompson is, therefore, to us at any rate, most welcome. He examines the problem from first principles and brings it, in more senses than one, down to earth from the starry heights to which it has tended to travel on the wings of enthusiasm. His early paragraph on 'Fundamentals', for example, very clearly sets out the essential elements of the 'escape velocity' or 'velocity of liberation' which has been the subject of a good deal of misunderstanding. He points out with simple truth that certain conditions of velocity at the 'operative' radius from the planet centre in relation to its force field must be satisfied before the vehicle achieves complete permanent escape from it—otherwise it will fall back. On the other hand, once this point is attained the vehicle will continue outwards 'automatically', so to speak, which involves abstruse calculations of fuel requirements. Put in this way it sounds like a self-evident truism but none the less the point has frequently been so clouded that sight of its simplicity has to a large extent been lost. Another point that he well brings out is the very large size which a 'space vehicle' will have to be—he speaks of 'hundreds of tons'—to satisfy the conditions in regard to weight of fuel etc. to be carried.

Summing It Up

The whole gist of the matter is admirably summed up in his 'Conclusions', in which , after a consideration of the various figures he has adduced earlier, he decides that flights to the planets are impossible with any of the chemical fuels now available and virtually so even with the most powerful of future hypothetical chemical rocket-fuels of which we have any knowledge. It all comes down in fact to the possibilities of atomic energy. This is nowadays looked upon as the universal panacea for all energy ills— somewhat akin to the 'lodestone' of the ancients—but on serious consideration the prospect of enclosing adequate power of an atomic nature within the limitations of a practicable vehicle seems at present to be hoplessly remote. As our author concludes, 'It is reasonably safe to assert that suitable methods of using nuclear energy must be developed, or man must remain in effect permanently earth-bound' and, as we have already suggested, the possibilities in that direction no man is at present in a position to state without venturing into the realms of prophecy.

On the other hand, though he points out that they do not greatly affect the basic problem, he does throw out the suggestion that 'space stations', or artificial satellites, offer a promising field for investigation. The idea of having a 'half-way house' on which to pause before jumping off again is, of course, undoubtedly attractive; though to the lay mind—among which in this respect we regretfully confess our own to be numbered—it does not present itself as a wholly practicable proposition. We do not know how the necessary caches of fuel are to be placed in them; nor indeed how they are to be located by the voyagers, particularly as their gravitational pull would, it would seem, be quite puny.

Paris and Le Bourget 1951

A Review by the Technical Editor of the More Interesting Exhibits at the Nineteenth Salon

Fig. 1.—The Paul Aubert Cigale Major is a new version of a pre-war light aeroplane. Its clean lines and neat engine cowling (which opens backward in two large panels, with two small inset upward opening doors for priming, etc.) show well in this view

The Nineteenth Salon International de l'Aéronautique was principally a British and French affair, although there were notable contributions also from the Netherlands, Italy and the U.S.A. As an exhibition, however, it was patchy and many of the exhibitors showed nothing new; some because of security restrictions, but others undoubtedly because they simply had nothing new to show after two years. The restrictions and economies of today were very much in evidence, and it was even surprising how some of the manufacturers have managed to exist at all since the end of the War.

France, in particular, has been subjected to a series of economic crises in the aeronautical industry and has suffered very greatly from vacillations of official policy. After the War tenders were put out for military, commercial and private types and, as a result, numerous prototypes were built, but the necessary production orders were a long time in coming. In some cases, worthwhile orders were placed early, but were later reduced or cancelled. An original order for twenty-five **SNCASE Armagnacs** was reduced to fifteen and, during the Salon, to eight. As another example, when a competition for a two-seater light trainer was outstandingly won by a private design, the **Sipa 90**, as opposed to a product from one of the nationalized factories, the decision was withheld for many months and a production order only placed after a very long delay.

Such, then, are the conditions under which the French constructors are working and it is really surprising that they were able to support the Salon as well as they did. Furthermore, they supported it in a realistic fashion, without the usual collection of optimistic mock-ups posed in fantastic attitudes which normally welcomes one upon entering the Grand Palais. Less realistic was the lack of technical information and photographs available on the majority of the stands.

Because of the date of the Salon this year it was impossible for us to prepare a report in time for our July issue and, therefore, we propose to deal in some detail with those items which interested us most, both at the Grand Palais and at the static and flying displays at Le Bourget. We are, further, restricting this review to new items—new either since the last Salon or since the 1950 S.B.A.C. Display. Even so, our review takes as much space as we can conveniently spare.

AEROPLANES AND HELICOPTERS

For ease of reference we will deal here with the aircraft alphabetically, in the order of their manufacturers and not in that of the importance of the exhibits and we will omit altogether reference to those stands where nothing novel was shown.

Although not exhibited at the Salon, the **Paul Aubert PA-204 Cigale Major** was shown and demonstrated at Le Bourget, FIG. 1. This is a very smart looking four-seater high-wing monoplane of wooden construction. Strictly speaking it is not a new type, since the fuselage is the same as a 1938 design, but a completely new wing has been developed. There are a number of novel and interesting features.

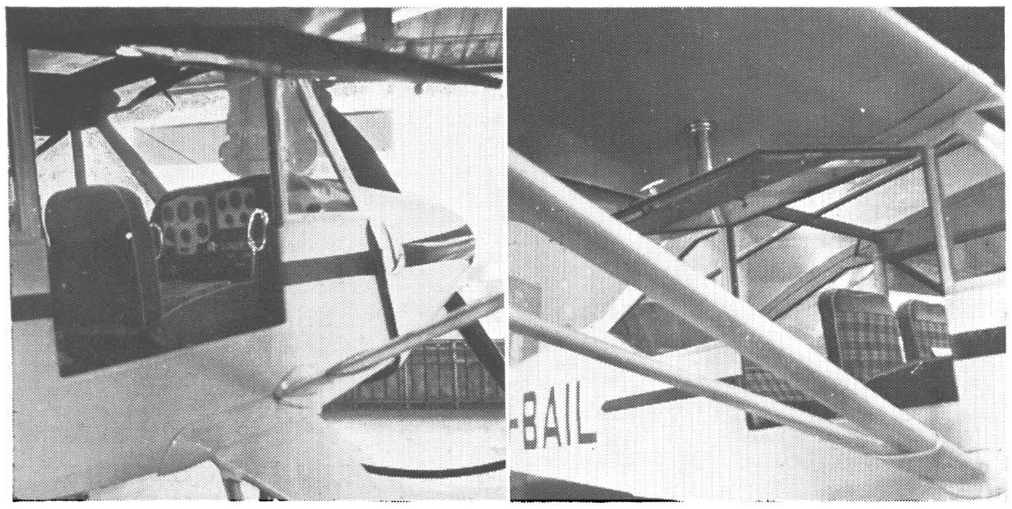


Fig. 2.—The capacious cabin and good all-round view of the Boisavia Mercurey are well shown here. Note the upward-opening doors that catch on to the fuel-tank gauge fairings. The generous instruments and separate spade-grip sticks can also be seen

The plywood-covered cantilever wing is built in one piece and has a moderate taper with elliptical tips. Of moderate thickness, there is a pronounced change of section and reduction of incidence toward the tips. Originally there were plain flaps and ailerons, but they have now been joined so that the whole trailing edge acts as ailerons, while it is lowerable to take-off and landing positions. The designer, M Aubert, claims that his wing has an innocuous stall and that the flaps produce a variable-incidence-cum-camber effect, so that the PA-204 can be brought in to land at low speed in its normal gliding attitude with the nose down. There is then a large change of attitude at touchdown, so giving a good cushioning and braking effect.

The fuselage is a plywood box with a steel tube engine mounting covered by large hinged panels giving good accessibility. Large lift-up doors make entry to the cabin easy and they are secured by long bolts when closed and a simple catch when open. Internal accommodation is spacious, although only fitted for test flying at present. There is a large locker at the rear of the cabin and one in each wing root between the spars. The cabin roof has numerous glazed panels and a large rear-view mirror is fitted—in all visibility is of an exceptional standard. Two roof panels give access to the top of the wing for filling the fuel tanks, which are some two feet outboard of the fuselage. All controls are mounted on ball-bearings, two separate sticks being carried on a cross-shaft just ahead of the seat. The flaps are operated by a spring-balanced lever working on a quadrant, with a release knob in the top, between the seats. A similar lever controls the adjustable tail plane, while a small lever in the roof operates a bungey balance for hands-off trimming. Full blind flying instruments and hydraulic dashpot brakes are fitted. The undercarriage is of the cantilever single leg type with shock-absorbers concealed in the fuselage under the seats. A neat item noted was the picketing points, complete with bungey shock-absorber loops, inside doors in the wing tips.

When demonstrated in flight the large rudder, incorporated to take full advantage of the slow flying characteristics, appeared to be rather sensitive at take-off. Slow flying under power was good. The change of attitude at touchdown appeared rather drastic for any but fairly experienced pilots. General manoeuvrability was good.

With a 140 h.p. Renault inverted engine the following performances are quoted: max. speed 245 km.p.h.; cruising speed 215-220 km.p.h.; landing speed 80 km.p.h.; range 1,200 km.; consumption 15-16 litres per 100 km.

Société Boisavia showed their **Mercurey** (FIG. 2) four-seater tourer on a rather obscure gallery stand. This is, in effect, the Cub/Auster formula re-proportioned on the lines of a larger aeroplane. It is a high-wing, strut-braced monoplane with a fabric-covered tubular fuselage, fabric-covered control surfaces and tail unit and a plywood-covered wooden wing, fin and tail plane. The vee-struts bracing the wing are of round tube with a fabric-covered balsa fairing—an old idea for economy in cost and weight that is not often seen today. Fixed tip slots and slotted flaps (operated by a handle and worm drive in the cabin roof), in conjunction with the untapered wing ought to give easy landing characteristics. Large upward-opening doors make entry simple and they catch on to the metal fairings of direct-reading float-type fuel gauges under the wing. Large transparent panels in the cabin roof give a good all-round view.

The cabin is reasonably roomy and is fitted with full dual controls. The seating is only fair, since comfortable seats are not a characteristic of French designs. There are two throttles, a push-pull central one and a rather flimsy lever on the left. A full range of instruments for blind flying is fitted.

Originally having a 140 h.p. Renault in-line, air-cooled engine, the Mercurey can be fitted with the 165 h.p. Continental or the 185 h.p. Lycoming—the latter being the version for which the following figures are given. Span 11.38 m.; length 7.10 m.; height 2.10 m.; wing area

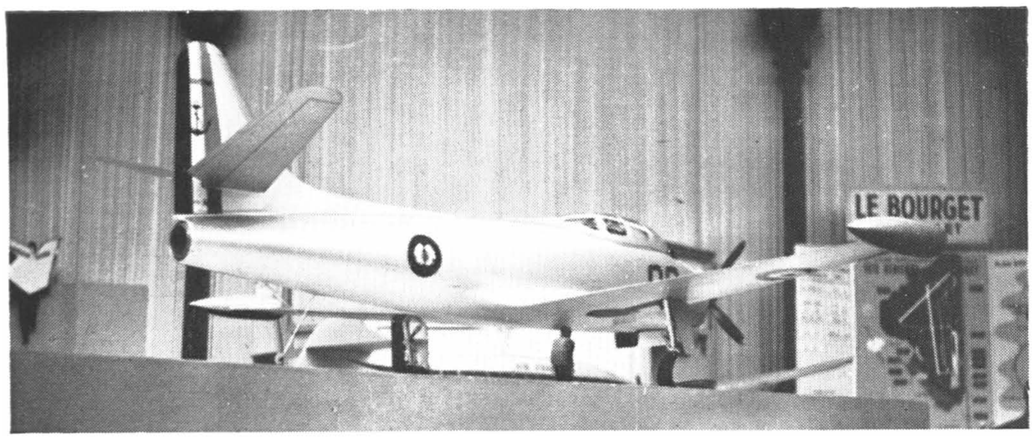


Fig. 3.—The Bréguet Vultur model reveals a clean aeroplane with rather short nose and long tail. The dihedral tail plane is presumably a means of increasing directional stability for carrier operation

18 sq. m.; tare weight 620 kg.; gross weight 1,190 kg.; max. speed 230 km.p.h.; cruising speed 210 km.p.h.; landing speed 65 km.p.h.; initial climb 4 m./sec.; ceiling 5,500 m.; range 1,200 km.; consumption 17 litres per 100 km. Take-off and landing runs are given as 135 m. and 60 m. respectively, but without specifying conditions.

The stand of **Louis Bréguet** showed only models and examples of **Rotol Propellers**, for which they hold the French licence. The military and civil versions of the '*Deux Ponts*' were shown by graphic models indicating the loads which could be carried. Two of these excellent aeroplanes were demonstrated at Le Bourget, where their take-off and landing runs were notably short, even allowing for their light load. The solidity of the flooring on this aeroplane is remarkable and the whole structure gives a very good impression of robustness, while the aerodynamic lines are exceptional for a cargo aeroplane. Twelve, known as the **Type 763**, and fitted with Pratt and Whitney R-2800-CA18 engines are going to Air France. The original prototype, now designated **Type 764**, has been equipped for trial as a long-range reconnaissance aeroplane for the French Navy and has all the latest radar equipment.

The **Type 960 Vultur**, which was expected at the Le Bourget flying display, was shown in model form, FIG. 3. It is a carrier strike aircraft with the unusual engine combination of an Armstrong-Siddeley Mamba and a Hispano-Suiza Nene. It is an ingeniuously arranged aircraft with the Mamba in the nose, side-by-side ejector seats ahead of the wing under a sliding canopy and with wing root air intakes for the Nene. The Vultur has a span of 16.6 m., a length of 13.2 m. and a gross weight of about 10,000 kg. The makers estimate a cruising speed of 400 km.p.h. on the Mamba and a maximum speed of 900 km.p.h. on both engines; landing speed is expected to be 150 km.p.h., ceiling 13,000 m. and endurance, cruising on the Mamba, 4 hours 20 mins.

The Bristol Aeroplane Company showed on its aeroplane stand a complete production **Type 171 Sycamore** helicopter, models of the **Type 173** twin-engined helicopter, the **Type 170 Mark 31 Freighter** and the **Type 175** air liner, together with structural components of the latter. The Type 171 was a noteworthy exhibit because it had been flown from Bristol and had alighted outside the Grand Palais.* Toward the end of the exhibition a photograph of the Type 173 on its first running trials was added to the model. Although the Type 170 has been flying for some years, we make no apology for showing, in FIG. 4, the new features, incorporated in the Mark 31.

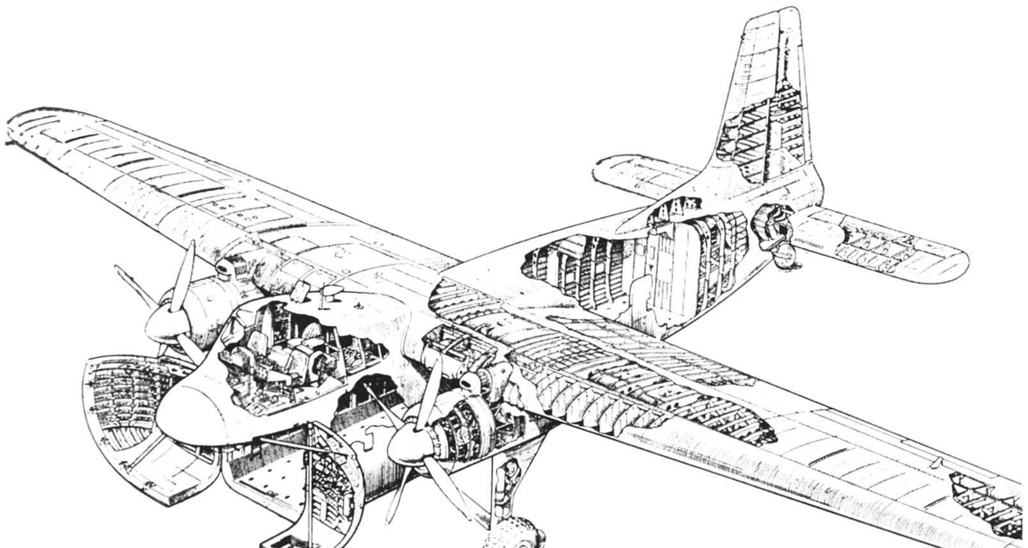


Fig. 4.—A Bristol cut-away drawing of the Type 170 Mark 31. New features are Hercules 734 engines, giving 2,000 h.p. for take-off, with twin oil coolers in the centre section; automatic pitch coarsening in the event of engine failure; a strengthened undercarriage; dorsal fin and larger tail plane; re-positioned nose door struts and larger rear bulkhead opening increase the load capacity; and increased fuel capacity of 1,170 gals.

The sections of the Type 175 airliner, now being built in quantity for B.O.A.C. were of considerable interest. A wing box spar section showed a structure with a smooth outer skin stiffened by an inner corrugated skin, plain web spars with extruded L-section booms and Warren truss interweb bracing taking the place of ribs. In manufacture, the skin is assembled first in jigs giving the correct curvature and accurate profile control. Thereafter, the webs and lastly the Warren trusses are assembled, still with the upper and lower skin surfaces as the control.

A fuselage panel illustrated how the sections of the skin are built up in small sub-assemblies complete with stringer and frame sections before joining into units. Again, the skin is used as the control. On this and the other Bristol parts, spin-dimpling is used instead of countersinking: this method eliminates on the one hand the surrounding groove in normal dimpling and on the other the reduction in skin thickness caused by countersinking. Spin-dimpling is done with a highly-polished mandrel turning at 2,000 r.p.m. and has so far been used on material up to 16 s.w.g. Much of the development work has been carried out by Bristol and the firm considers there are many further possibilities.

A leading-edge section showing the double skin for wing heating was of interest as, in this case, extensive use was made of **Redux** for bonding the outer and inner skins. Plastic sheeting was used to lag the ducts along the skin and the spar.

Not shown at the Salon, but exhibited at Le Bourget in the static park on the day of the flying display the 1951 model of the **Cessna 170** was a welcome example of modern American light aircraft practice, FIG. 5. This all-metal four-seater presents a combination of good engineering design and of passenger comfort entirely unknown in European light aircraft—the nearest approach to it being, perhaps, the Nord Norécrin.

The Cessna 170 follows the combination of a high-wing and rounded fuselage of previous types from that company, but the forward view has been greatly improved. The wing is of parallel chord for half the span, with a slight taper on the outer portions. A simplified all-metal structure is used with a minimum number of large component units. A single streamline tube braces the front spar. Ailerons and flaps are metal covered, with embossed beads taking the place of ribs. There is a pronounced washout, with a quite marked twist in the trailing edge of the ailerons. The fuselage is a simple rounded monocoque, again with the minimum number of components. One wonders whether the rounded underside affects the touchdown, since we have usually found that a flat-bottomed fuselage gives a beneficial cushion effect for landing. The fixed tail surfaces are simple cantilever structures and the beaded skin is again used for control surfaces. The main landing gear relies on spring steel legs for shock absorbing, while the steerable tail wheel is mounted on a leaf spring. Such a structure as this is naturally easy to maintain, but care has also been taken in detail design to ensure simple servicing. For instance, the engine cowling has large robust panels held by a few toggle fasteners and is completely removable without touching the airscrew.

Entry to the cabin is through a forward-opening door and, although the step is rather high, it presents less difficulty than usual to feminine passengers. The seats are remarkably comfortable, with both springs and latex foam cushions, and are fully adjustable for pilots from 5 ft. 2 in. to 6 ft. 6 in. The dash is laid out with a full range of instruments and V.H.F. radio—and there is even a cigar lighter and an ashtray. The whole cabin decor and equipment compare favourably with a luxury car. The dual controls are wheels mounted in the dash and plate pedals with the usual dashpot hydraulic brakes on both sets. Forward and downward the view is perfect, but there are no transparent roof panels, so that upward and rearward the Cessna is blind.

In addition to this civil model, the firm is manufacturing the L-19A with a 213 h.p. Continental engine for the U.S.A.F. The civil machine has, of course, the Continental C-145-2 flat-six air-cooled engine of 170 h.p. Principal characteristics are: span 36 ft. 0 in.; length 25 ft. 0 in.; height 6 ft. 7 in.; wing area 174 sq. ft.; tare weight 1,185 lb.; gross weight 2,200 lb.; max. speed 140 m.p.h.; cruising speed 120 m.p.h.; initial climb 670 ft./min.; service ceiling 15,500 ft.; endurance 4 hours.*

Marcel Dassault exhibited at the Grand Palais a reconnaissance version of the **MD-450 Ouragan** in the identical spot where the prototype was shown in 1949. The new variant has camera ports in the underside of the

Fig. 5.—A type that is lacking in Great Britain, the four-seater luxury aircraft of good performance. The Cessna 170 for 1951 is a very clean little aeroplane in which the pilot's view is considerably better than on some of the company's earlier models

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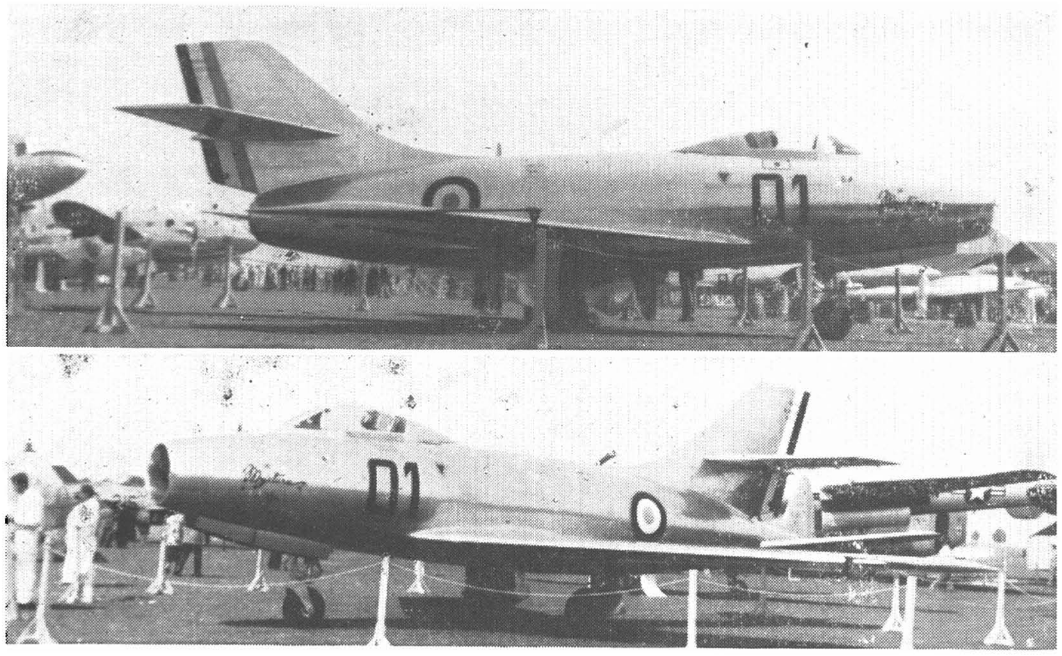
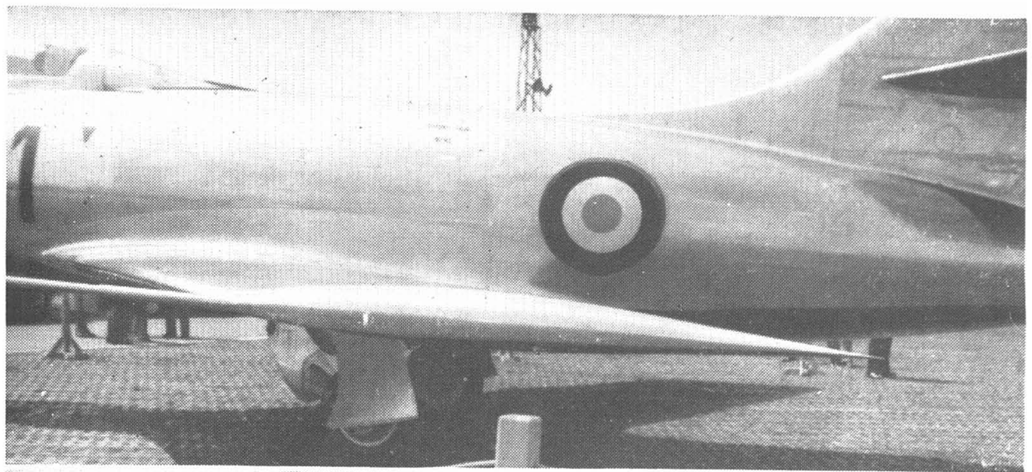
* The Bristol Type 171 was very fully dealt with in 'Notes on the Development of the Bristol 171 Helicopter,' by F. W. Stokes, March 1951, pp. 67-71.

* The Cessna 170 was exhibited by the French agents, Air-Tourist, 70 rue de Ponthieu, Paris.





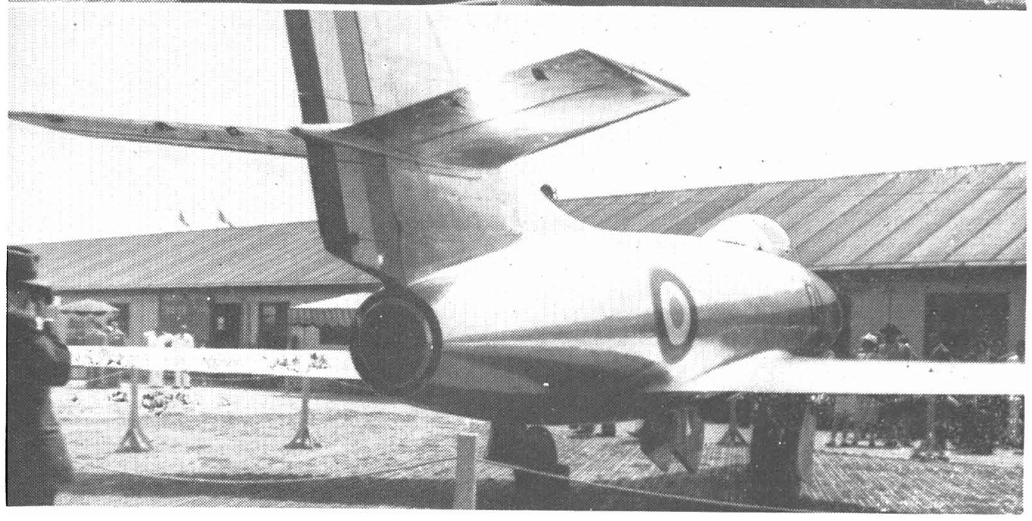


Fig. 6 (above).—These two general views of the Marcel Dassault Mystère show its proportions well and also indicate its surprising resemblance to the MiG-15

Fig. 7 (upper right).—This close-up of the wingtip of the Mystère shows the wing section clearly and the noticeable washout of incidence. The outline of the wing root fillet well up the fuselage side is visible, although, as can be seen, the actual radiused portion is small

Fig. 8 (lower right).—The elevator of the Mystère has a generous tab area. The sharp wing root angle is again obvious here and the narrow track can be seen too. The main legs are mounted aft of the spar and the wheels lie in the bottom of the fuselage

wing and in the rear fuselage, wing-tip and underwing fuel tanks, two V.H.F. aerials beside the windscreen and di-pole aerials in the fin. Two further versions of the type are being prepared: the **Aladin**, a single-seater all-weather fighter with radar in the nose and side intakes; and the **Harmattan**, a two-seater all-weather machine.

The much-publicized and carefully shrouded **MD-452 Mystère**, FIGS. 6, 7 and 8, appeared in the static park at Le Bourget on the last day of the show and was demonstrated in flight by Colonel Rozanoff.

As had been expected, this aeroplane is simply a swept-wing version of the Ouragan. The limited examination permitted revealed good workmanship with particularly good skinning of the torsion-box portion of the wing. The leading edge, on the other hand, was rather less perfect in contour than the rest of the aeroplane. There are spars at about 30 per cent, 55 per cent and 65 per cent chord—the latter manifestly carrying the aileron and flap hinge brackets, although these surfaces are actually less than one-third of the main chord. The wing section is of the laminar flow type with maximum thickness at about half chord and a small trailing-edge angle, but it is not a thin section—at a guess over 15 per cent. Considerable washout of incidence was noticeable. The wing-root fillets were curious because they were large panels and yet were of remarkably small radius. It looked rather as if the designer had been prepared for a large-radius fillet, but had found it unnecessary—or had removed it because of airflow troubles.

The trailing edges of the ailerons projected about two inches aft of the wing and it may be that these were temporary. We understand that just before the flying display there had been some trouble with the power-operated controls and that they had been removed, so there may well have been temporary fitment of larger ailerons.

It may be, of course, that the additional aileron chord has been added to overcome 'Dutch roll' and to provide adequate lateral control to overcome the dihedral effect of yaw at low speeds.

The tail unit, generally similar to that of the Ouragan, looked particularly neat, with close-fitting fillets on the adjustable tail plane. The two-piece rudder had trimming strips on the smaller lower portion only. A large number of rows of rivets running in several directions across the skin of the lower part of the fin indicated some difficulty in stiffening this highly-stressed structure.

The rear fuselage had ample air space round the Nene's jet pipe and fitting of the larger outlet for the Tay, or an after-burner, should be a simple matter. With its present power unit the Mystère has been said, semi-officially, to have reached 1,020 km.p.h. (633 m.p.h.) at sea-level and also to be 'more than 80 km.p.h. faster than the Ouragan', which would bring it up to about 650 m.p.h. During the flight demonstration it was flown very fast and these claims do not seem at all impossible. Incidentally, the wing loading is reputedly lower than that of the Ouragan because the wing area has been increased due to the geometry of the sweepback. A landing speed 10 km.p.h. less than that for the earlier type is quoted—which would be very little over 100 m.p.h.

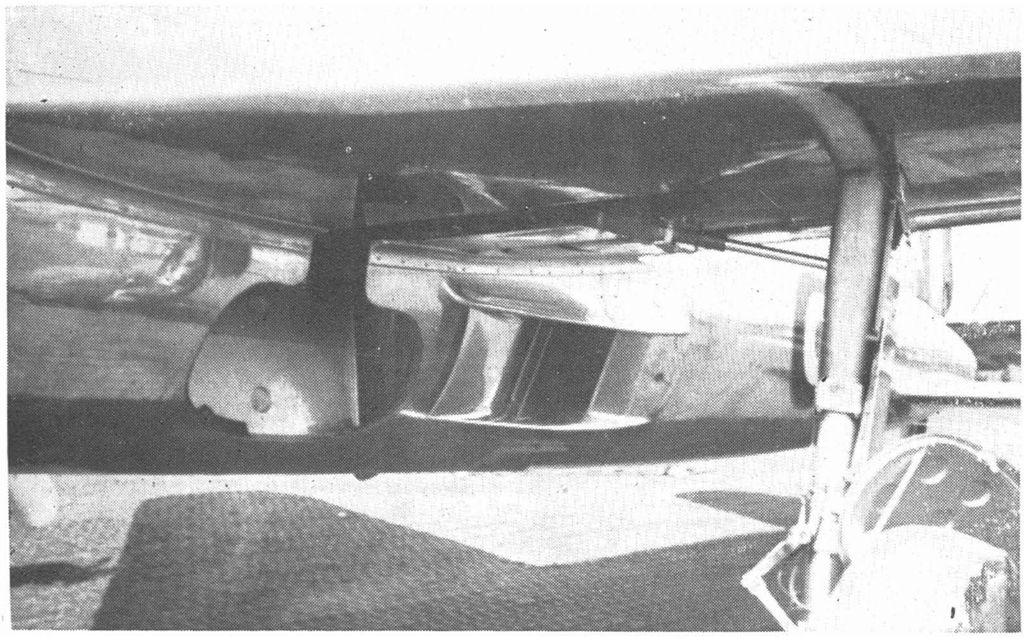


Fig. 9.—The air intakes for the latest version of the SO-6021 Espadon are unique. Shielded above and below by a fillet, there is a boundary layer bleed, twin guide vanes, the main entry and an in-turned lip at the rear. The action of all these parts on the air flow is obscure, but the Espadon certainly flew fast, so that they must work well. Take-off and landing speeds appeared to be much too high for any operational use

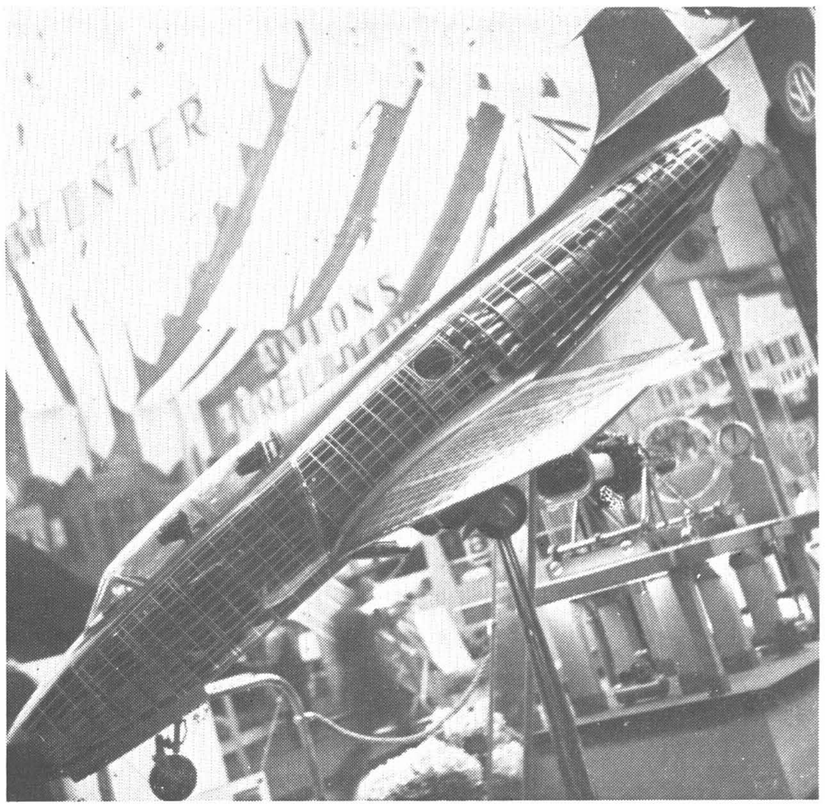


Fig. 10.—The model of the Fiat G-80 fighter-trainer revealed a tidy aeroplane with a conventional structure. There are access panels to the front of the D.H. Goblin engine, but tail removal is the main method of reaching the engine and of taking it out

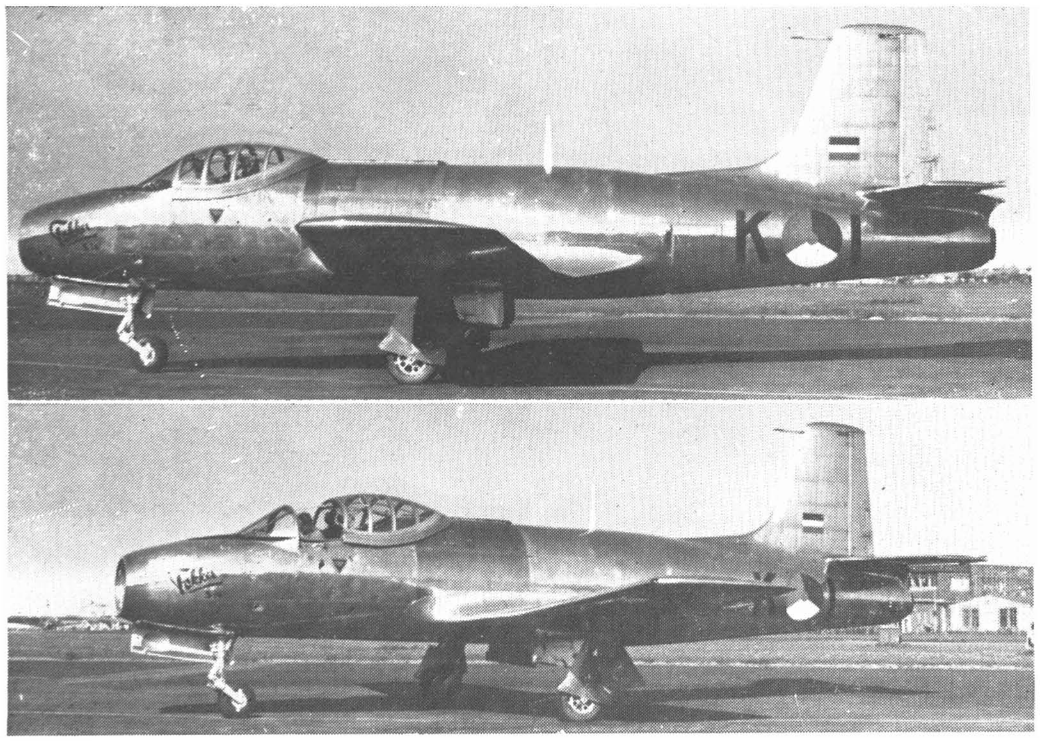


Fig. 11.—The Fokker S-14 jet trainer is much bulkier than the Fiat one, but has the several advantages of side-by-side seating. These views, in default of flying ones, show it to best advantage and give a good idea of its lines

When demonstrated, the Mystère was shown to have good acceleration and a very reasonable take-off and landing run for a modern fighter. As is usual, rolling manoeuvres were particularly facile; but general manoeuvrability was good and the space required seemed equivalent to that of our own swept-wing types. Climb seemed to be good and after a high-speed run the aeroplane must have reached well over 10,000 ft. in a nearly vertical zoom. The likeness of this aeroplane to the MiG-15, despite the lower wing position, noticeable on the ground, becomes striking when in the air, particularly when the fuselage air brakes are opened.

Fiat exhibited, on the combined Italian stand, the latest of their piston-engined fighter trainers, the **G-59-4B** and a beautiful model of the **G-80** jet fighter trainer, together with the wing and tail unit of the first protype which is almost completed. Both types are the nearest that Italy has been allowed to design in the way of fighters since the war. The G-59-4B has a Rolls-Royce Merlin 500 engine and the cockpits are now covered by two bulged sliding hoods like the Spitfire Trainer, with a transparent tunnel between, which should give a better all-round view than did the hinged canopy on earlier models. The **G-80**, FIG. 10, is a neat, if conventional, jet aeroplane with side air intakes and an unswept wing. The prototype, will have a Goblin engine, but a Nene version is also projected.

The **Fokker** company made the largest contribution of new airframes by showing the **S-14** jet trainer at the Salon and the **S-13** crew trainer at Le Bourget.

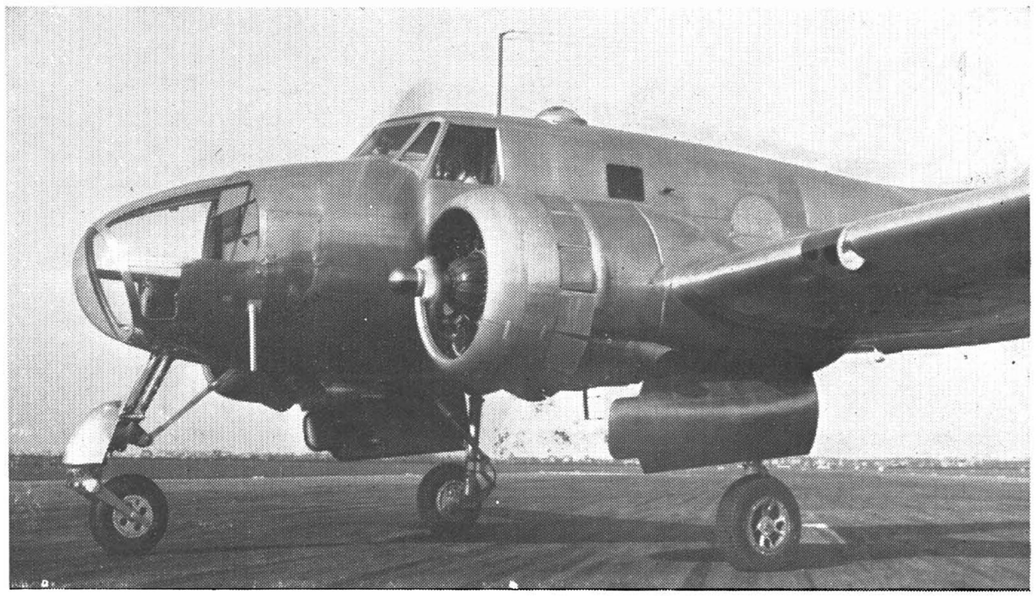


Fig. 12.—The Fokker S-13 crew trainer, with Pratt and Whitney Wasp Junior engines, has a very tall undercarriage, which the makers blame jointly on having to use two-bladed airscrews and having to conform to A.P. 970 requirements for ground clearance. It is a workmanlike job and well thought of by pilots who have flown it

The S-14 (FIG. 11) is the second jet trainer to have been designed as such and not to have been adapted from a fighter—the first was the rather unsuccessful SNCASO SO-6000 of 1946. The design was prepared as part of the Western Union defence programme to provide a true side-by-side trainer that would facilitate teaching the peculiar handling problems of jet aircraft. Because it was decided to give ample room for side-by-side seating, and also because a normal endurance of three hours was required, the S-14 is a bulky aeroplane. This size has given rise to rumours that it could be adapted to take a more powerful engine and become an all-weather fighter; but the designers deny this and maintain that the entirely different requirements of a fighter necessitate a completely fresh approach to the problem. It is of interest to note that Fokkers have designed their new aeroplanes to meet A.P. 970 (the official British military requirements) and that they have standardized on British ancillary equipment wherever possible—Dowty, Hymatic, Martin-Baker, etc.

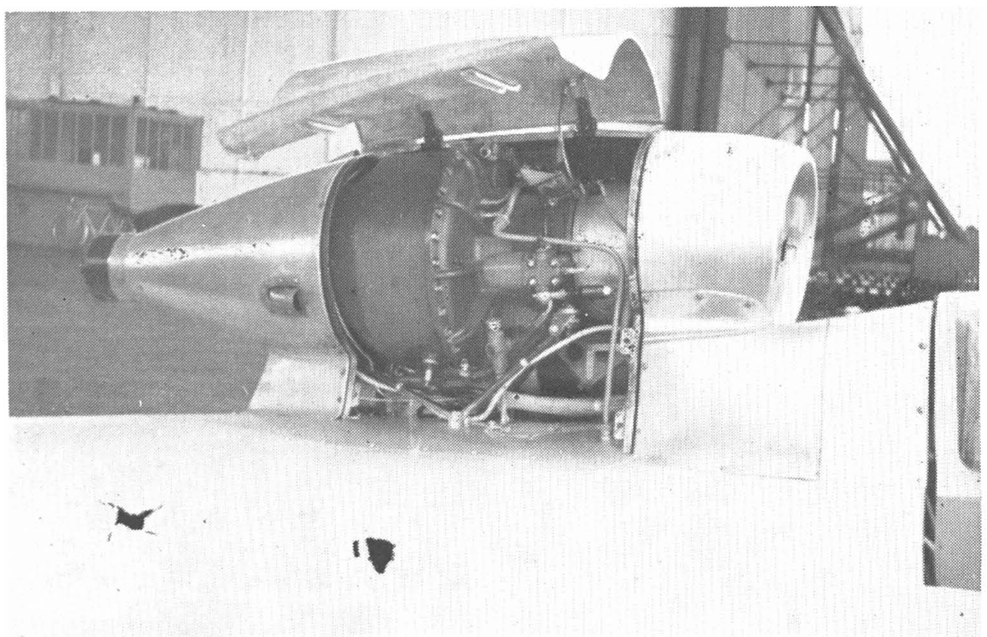


Fig. 13.—The simplicity of a Turbomeca engine installation is well shown by this photo of the Cyclope nacelle. Practically every part of the engine is accessible with the two cowlings raised

In its general lay-out the S-14 is conventional and aerodynamic design is good. The large, electrically-operated, sliding hood is robust enough for normal air loads and, after jettisoning allows exit by ejector seat for both passengers. The all-round view is excellent, despite the sturdy hood frame. The wing is of relatively thick section so as to give pleasant and safe stalling characteristics for student pilots—another reason why conversion to a fighter would be unsatisfactory. The wing is designed to hold the fuel, with two 90 Imp. gal. tanks in the centre section and 50 gal. and 60 gal. tanks in each outer plane. Split flaps are fitted between fuselage and ailerons, operated by a torsion shaft and toggle links. The ailerons have sealed pressure balances, with spring tabs. The latter have the torsion-bar type of spring, and the rather long lever arm needed for its operation is covered by a fairly bulky fairing.

The fuselage has a nose intake with a long divided duct and one was surprised to find mushroom-head rivets in this duct and closely-spaced tie rods bracing it. Apparently the latter were a temporary expedient to overcome panting. The engine bay, aft of the cockpit, is covered with stainless-steel sheet. The skinning of the rear fuselage and tail unit on this prototype was not good; but this may have been due, in some measure, to the vicissitudes of the project, which was shelved for some time.

The undercarriage is decidedly complicated. The nose-wheel has a lever action with a welded steel leg and fork, **Dowty** liquid-spring shock absorber and Marstrand twin-contact tyre. Retraction is forward by a jack operating directly on the top of the leg. The main legs have parallel linkages, which were made necessary by the need for mounting them aft of the 40 per cent chord main spar, while retaining a wheel contact ahead of this line. The units are made up from 55 ton/sq. in. weldable steel, heat-treated after welding, and liquid-spring shock-absorbers are again used. The two-piece wheel fairings and the wheel doors, the latter operated by a long unsupported tubular arm, are complicated and unattractive—they were, in fact, the cause of the undercarriage jamming on the aircraft's first flight.

An unusual feature is the use of a pneumatic system for the ancillary services: undercarriage, flaps, dive recovery brakes (under the wing), and main air brakes (triple fuselage doors), together with the usual British differential pneumatic wheel brakes and gun-firing gear—when fitted.

In general, maintenance was given a high place in the design. A series of ample doors under the fuselage allow full access to control runs, piping, flap jack, air-brake jacks and restrictors and the Derwent 5 engine. Turbine blade inspection can be carried out by plugging in a spotlight and shining it up the jet pipe, but complete tail removal is fairly simple. The engine is lifted out upward without disturbing the tail.

Estimated figures for the S-14 are as follows: span 12 m. (39 ft. 5 in.); length 13·3 m. (43 ft. 8 in.); height 4·7 m. (15 ft. 4 in.); wing area 31·8 sq. m, (342 sq. ft.); tare weight 3,550 kg. (7,820 lb.); gross weight 5,100 kg. (11.250 lb.); max. speed at 7,600 m. (25,000 ft.), 710 km.p.h. (440 m.p.h.), cruising speed 640 km.p.h. (400 m.p.h.); initial climb 17·7 m./sec. (3,500 ft./min.); climb to 7,600 m. (25,000 ft.) in 10·9 mins.; service ceiling 12,200 m. (40,000 ft.); take-off to 15 m. (50 ft.), 920 m. (1,000 yds.).

The **Fokker S-13** crew trainer (FIG. 12) is a conventional twin-engined low-wing monoplane—apart from an unusually long undercarriage necessitated by the clearance requirements for its two-bladed airscrews. It is a sturdy looking aeroplane, soundly constructed and reputed to fly well. Its fuselage is roomy and has a bomber's station in the nose, dual

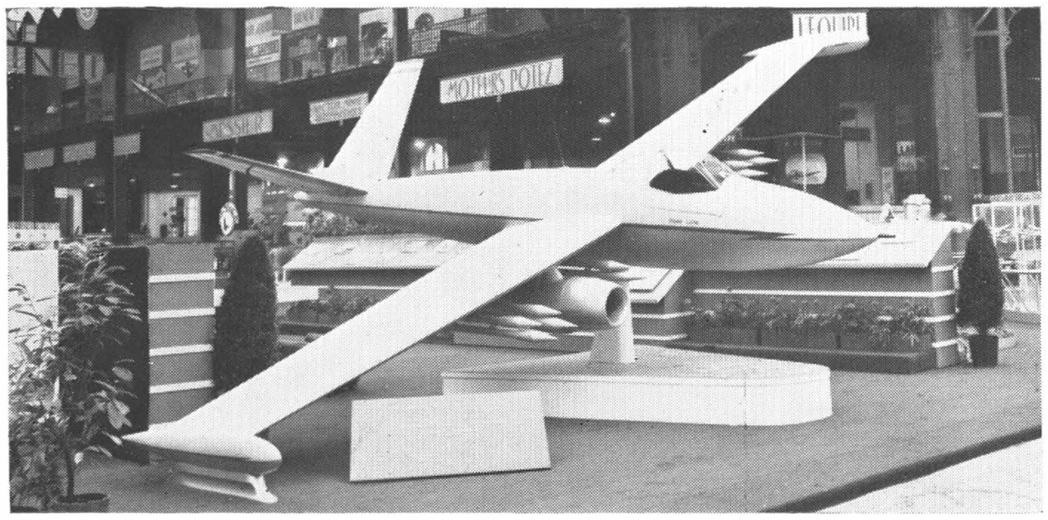


Fig. 14.—The Fouga CM-8-2R Lutin is another variant of the basic sailplane design. The undercarriage is fully retractable in this version, the main wheels into the fuselage and the skids into the wingtip fairings. The dummy rockets were mounted to indicate the projected CM-821-R, a ground-attack trainer with two 400 kg. thrust Marboré engines and an estimated speed of 750 km.p.h. at a weight of 2,900 kg.

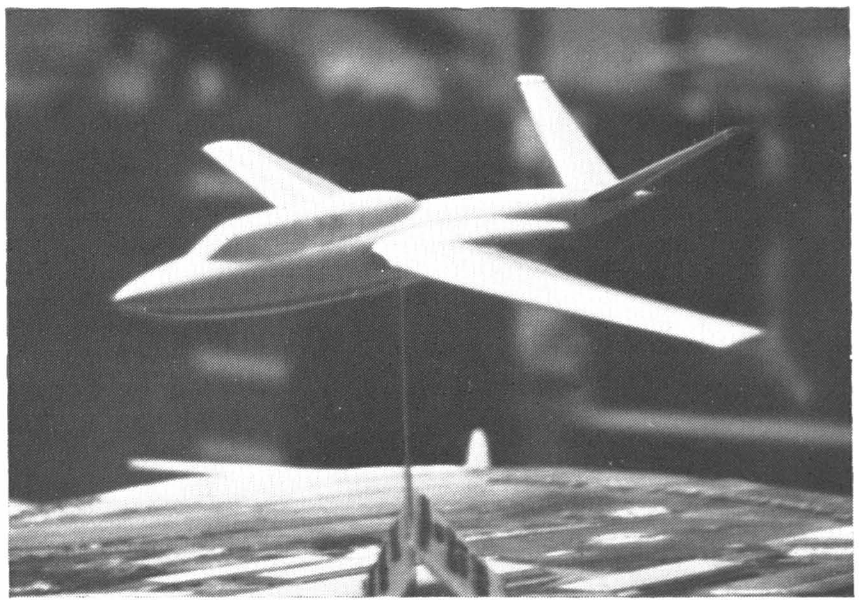


Fig. 15.—The model of the Fouga CM-170R twin-jet fighter-trainer revealed a break from previous practice. Although the yaw-pitch tail and the wing proportions are similar, the long nose and the wing root installation of the Marboré engines are new. One prototype has been ordered by the Ministère de l'Air

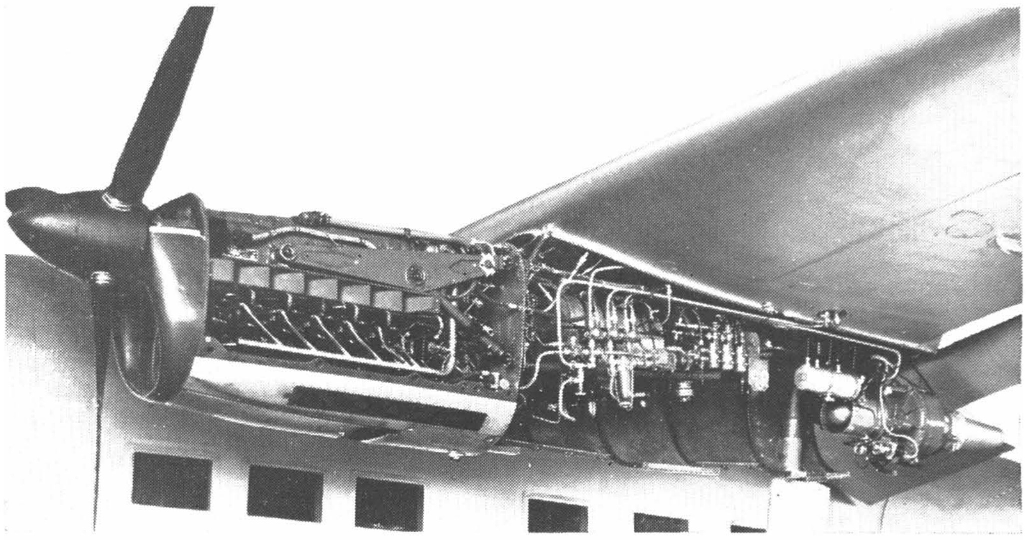


Fig. 16.—The port nacelle of a Fouga CM-101R with the outboard cowling removed to show the installation of an auxiliary Turbomeca Piméné. Air is ducted to it from a scoop in the bottom of the nacelle

control, if required, and stations for four radio operators or navigators.

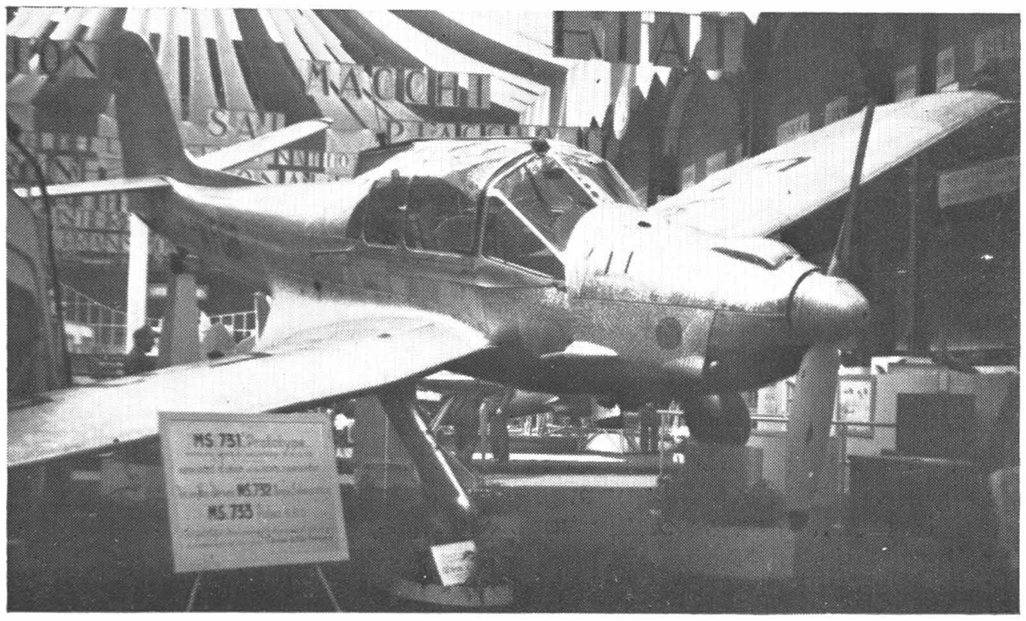
Fouga et Cie., the present company of M. Pierre Mauboussin, was well represented by its light jet aircraft. This work of adapting the jet engine to small, easily piloted designs is one of the most important developments of the last two or three years. The first machine, the Cyclone, was shown at the 1949 Salon and was simply a sailplane with a Turbomeca engine added to it. Since that date several types have been built—necessarily based on the Fouga sailplane airframes in order to keep down expense, but practical light aircraft nevertheless.

The two developments of the Cyclone, the **Cyclope I** and **Cyclope II** were flown at Le Bourget and gave a remarkable demonstration of speed and manoeuvrability. Their slender sailplane lines probably increased the impression of speed, as did the rather high-pitched whistle of their engines, but even so they are considerably faster than any other aeroplane of comparable size. The structure is orthodox sailplane practice and the tiny cockpit is typical, apart from the addition of the engine instruments and controls. The wing is fitted with plain flaps and quadrant-type dive brakes. The bicycle style undercarriage one imagines has been adopted of necessity rather than desire. It must have been purely because the sailplane fuselage was being used that the cumbersome expedient of fixed main and nose wheels together with retractable tip skids, and their attendant fairings, was used. Engine accessibility is outstanding, as can be seen from FIG. 13.

Characteristics for the Cyclope II, which has the Turbomeca Palas of 160 kg. thrust (as opposed to the 110 kg. thrust Piméné in the Mark I) are as follows: span 8.76 m.; length 6.66 m.; height 1.78 m.; wing area 9.8 sq. m.; aspect ratio 7.7; tare weight 429 kg.; gross weight 624 kg.; max. speed, at 4,000 m., 350 km.p.h.; initial climb 7.5 m./sec.; service ceiling 9,000 m.; still air range, at 4,000 m., 300 km.; take-off to 20 m., 300 m.

The range penalty of the jet engine can be seen, since the fuel load is 112 kg.

At the Grand Palais was exhibited a twin-jet racer, the **CM-8-2R Lutin,** the effect of which was rather spoiled by the last-minute addition of dummy rockets and machine gun—a rather misguided attempt to indicate the possibilities of a 'scaled-up' version for ground attack. As can be seen from FIG. 14, the sailplane tradition has been preserved, with the slender plywood fuselage and tiny cockpit. The combined yaw-pitch tail controls and the bicycle undercarriage of the earlier types have also been preserved. The Palas engines are arranged in standard 'power-pods' under the wing. These units have been developed as a joint effort by Fouga, Turbomeca and SNCASO for fitment also as emergency power packs for



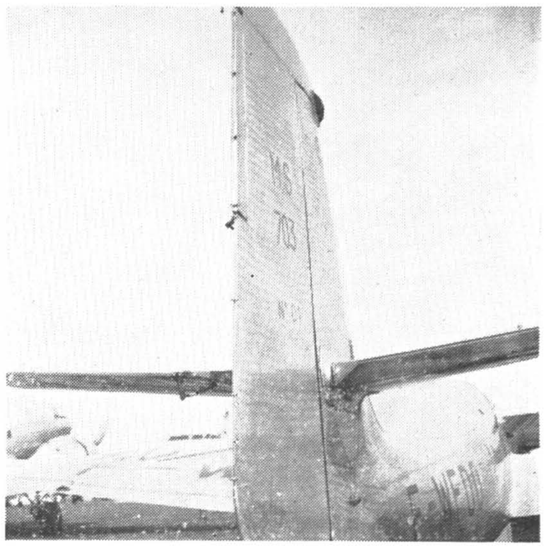


Fig. 17.—Although only the engine and the undercarriage are different, the Morane-Saulnier MS-732, upper left, looks more attractive than the MS-733 that is shown below. The aerodynamic value of the undercarriage retraction must be nil. On the right is a typical Morane-Saulnier tail unit with its 'split' tailing edge

larger transports. One unit is at present undergoing trials on a Douglas C-47 where, by mounting it under the centre section, it is hoped to improve take-off and single-engined performance.

Characteristics and estimated performance for the Lutin with a total thrust of 320 kg. are as follows: span 8·85 m.; length 6·85 m.; wing area 9·9. sq. m.; tare weight 550 kg.; gross weight 983 kg.; max. speed 500 km.p.h.; initial climb 20 m./sec.

A model of the **CM-170R** twin-jet trainer (FIG. 15) showed a still more practical application of the small jet engine.

In addition to work on the standard power egg, the Fouga company has installed Piméné engines in the nacelles of their **CM-101R** twin-engined feeder liner. The weight of such an installation is roughly equivalent to two passengers, while the extra thrust it produces allows for a take-off weight increase amounting to six—a net gain of four passengers. The jet engines are, of course, of help in single-engined flight as well as for take-off. The installation is shown in FIG. 16.

The **Hurel-Dubois HD-10** experimental high-aspect ratio monoplane, which missed the 1949 Salon, although it was flown at Orly, was exhibited. This aircraft, which has an aspect ratio of 32, is a flying model for a large cargo aeroplane, the HD-31, which will have a ratio of 20·5. These wings are arranged with large extension flaps and are braced at about mid-span by aerofoil-section struts that contribute materially to the lift. While the advantages of ultra high aspect ratios are undeniable for range and economical cruising performance, one feels that the structural penalties and problems involved are excessive. Nevertheless, the French Air Ministry—somewhat characteristically—is interested in the scheme and has ordered a prototype.

Morane-Saulnier exhibited at the Grand Palais the **MS-732** and at Le Bourget the **MS-733**, prototypes built to a ministry specification akin to that for the Prentice. The result is a rather cumbersome aeroplane with two side-by-side seats and a rear one under a large glazed canopy. The main differences between the two prototypes are that the former has a 250 h.p. Argus-Salmson 8-AS-02 engine and a neat cantilever fixed undercarriage, while the latter has a 240 h.p. Potez 6D-01 8-AS-O2 and a clumsy semi-retractable undercarriage carried in huge blisters under the wing. One imagines that the former is Morane-Saulnier's own idea, while the latter fulfils a military requirement for giving pupils experience of retraction drill. Like most Morane-Saulnier types, the fuselage is made from three long panels, top and sides, assembled longitudinally. The wing structure is sound but conventional. An unusual feature noted was the method of making the trailing edges of the control surfaces. The two light-alloy skins are separated by a flat (or frustum) section strip about 3/16 in. thick and are left to project about 1/4 in. aft of the strip. Presumably, this 'overhang' is then available for adjustment if correction of hinge moments or trimming should be necessary. Both main control and tab surfaces were finished in this way.

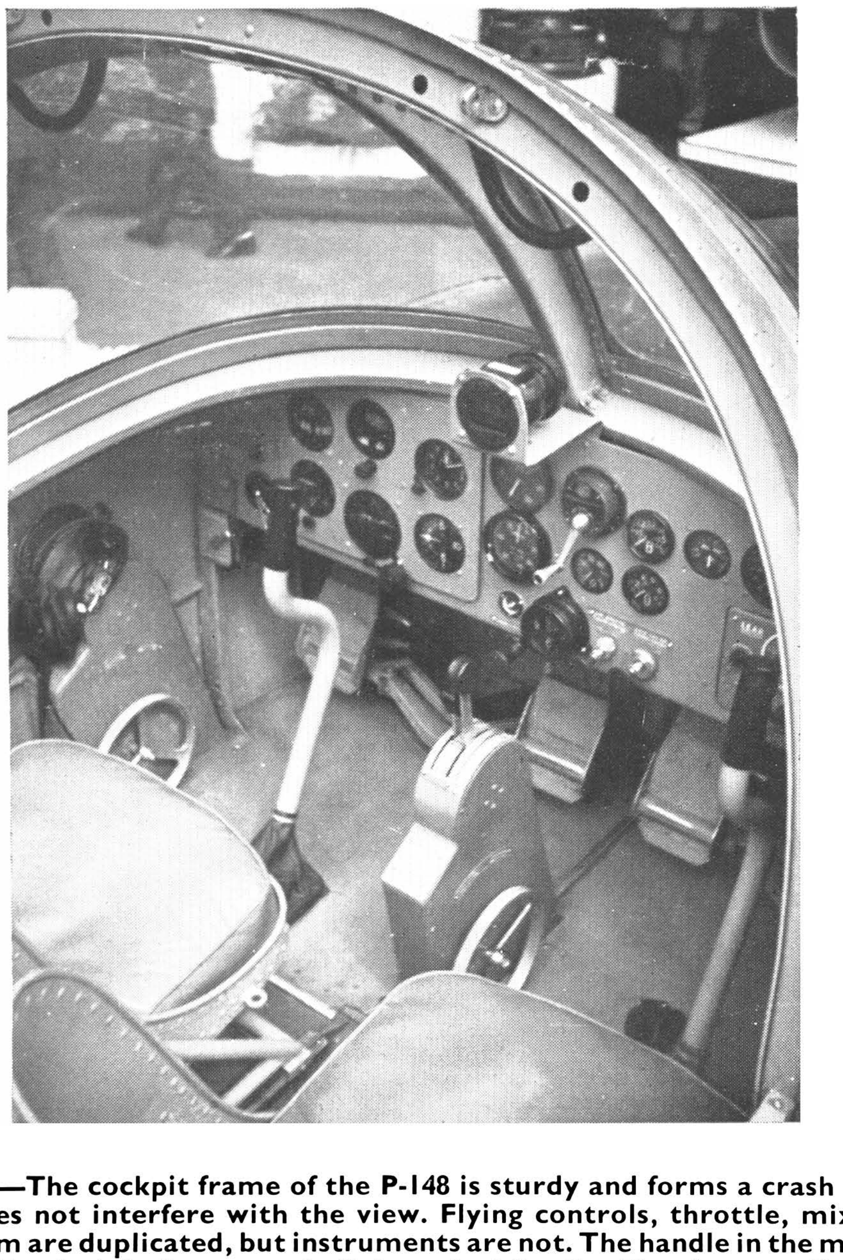


Fig. 19.—The cockpit frame of the P-148 is sturdy and forms a crash arch, but does not interfere with the view. Flying controls, throttle, mixture and trim are duplicated, but instruments are not. The handle in the middle of the dash is the manual pitch control for the Piaggio propeller

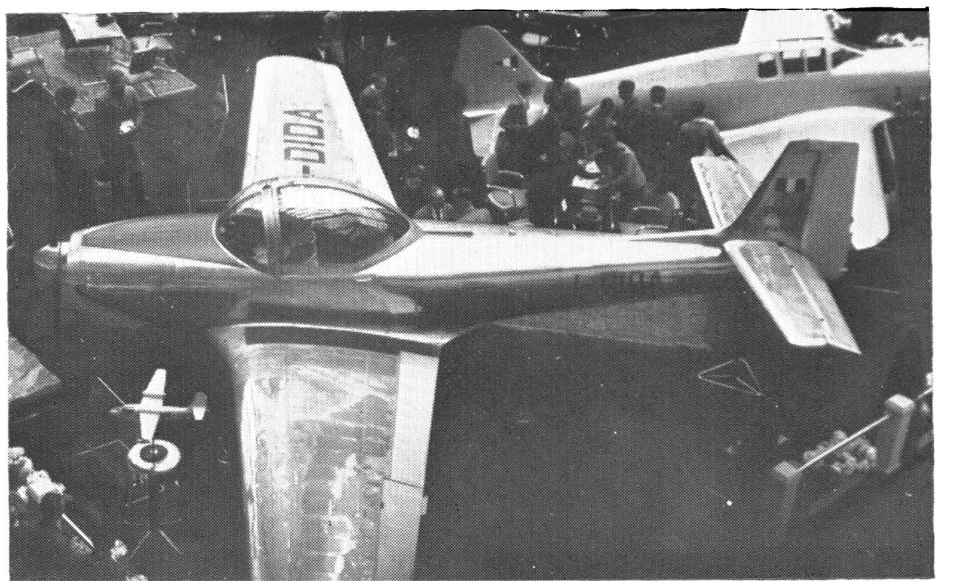


Fig. 18.—The Piaggio P-148 is probably the best-looking three-seater trainer yet built. By using a long rear fuselage the designer seems to have overcome the awkward spinning characteristics common in such layouts, where the large cockpit canopy interferes with the air flow

Figures quoted for the two types are as follows, the MS-732 is given first and the MS-733 in brackets where different: span 11·35 m.; length 9·16 (9·46 m.); height 3·45 m.; wing area 20·4 sq. m.; tare weight, three-seater, 1,245 kg. (1,238 kg.); gross weight 1,677 kg. (1,670 kg.); max. speed sea-level, 260 km.p.h. (250 m.p.h.); cruising speed, sea-level 220 km.p.h. (215 km.p.h.); stalling speed 100 km.p.h.; initial climb 4·40 m./sec. (4·10 m./sec.); service ceiling 5,400 m. (5,000 m.); endurance, normal 4 hrs. (4 hrs. 30 mins.), aerobatic 2 hrs. 40 mins. (2 hrs. 45 mins.).

Hidden in a remote gallery was an interesting prototype—or rather part of one—for a delta-wing design. This was the **Payen Pa 49 Katy**, the latest idea of the enthusiast who designed the various Flêchair prototypes which, before the War, seemed so weird, but which look remarkably 'conventional' today! The present design has a span of about twenty feet and closely resembles the Lippisch delta prototype, made late in the War. It is to have a Piméné engine in the tail with a nose intake. As shown, the slotted control surfaces were missing, but their hinge brackets revealed that there were large balance areas. The large fin carried a narrow-chord tapering rudder with unshielded leading edge. The aeroplane looked quite practical, but the workmanship was poor, as it had been built by a group of enthusiastic amateurs. The designed maximum speed was given, rather optimistically, as 370 km.p.h.

The **Piaggio P-148**, on the combined Italian stand, was an exception to the rule that a three-seater trainer must be ungraceful, FIG. 18. The manner in which the slender all-metal fuselage has been combined with a large teardrop canopy to provide ample accommodation while preserving good aerodynamic qualities is both simple and ingenious. It is noticeable, too, that the rear fuselage is longer than is general practice today, so that there is a good lever arm for the tail surfaces and ample space between wing and tail plane. This aeroplane has flown some 190 hours, but was not, unfortunately, available for demonstration during the Salon. The makers, however, claim that there have been no troubles with spinning—as is so common with this formula—and they also say that no modifications whatever have been required as a result of flight trials. The stressed-skin structure is conventional, with frames and stringers, but without longerons. The 190 h.p. flat-six Continental engine is carried on a welded steel-tube mounting and is very accessible inside its easily-opened cowling.

The wing is simply tapered with a small leading edge root fillet and considerable washout of incidence. There are no spoilers at the wing root so, presumably, the washout has been effective in retaining lift at the tip after the remainder of the wing has stalled. The ailerons, like the other control surfaces, have slightly inset hinges and are of fabric-covered light-alloy construction. Plain flaps (also fabric covered) are fitted and are operated by a five-position lever in the cockpit. The main and tail legs are oleo-pneumatic.

The windscreen frame, and that of the easily-opened canopy, are robustly made built-up members capable of withstanding 'turnover' loads. Despite this, the members do not interfere with the view from either seat, which is outstanding in every direction. The hood is easily opened from inside or outside and is jettisonable, although it cannot be opened in flight. The P-148 was designed primarily as a trainer and it is in that light that its cockpit layout should be viewed, but it would obviously make a most pleasant tourer. The two pilots' seats are well positioned with ample space around them, but the present rear seat induces an uncomfortable knees-up attitude, although there is space for a different arrangement in a true personal aircraft adaptation. Instrumentation is very complete, with the blind flying panel in front of the left-hand seat and V.H.F. radio in front of the right-hand one. Flying controls, throttle, mixture and tail trim are duplicated, but the manual control for the Piaggio propeller is in the centre of the dash, FIG. 19. The seats are very easily adjusted on runners and are arranged to take the back-pack parachutes common in Italy. The safety

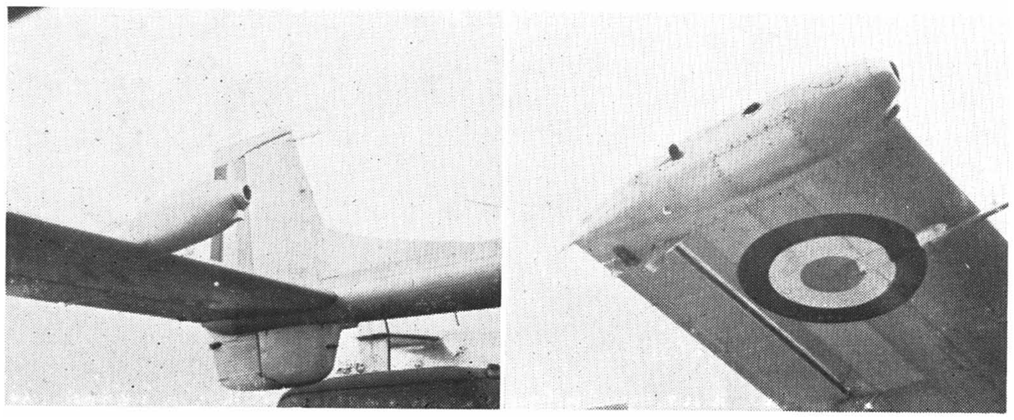


Fig. 20.—Now well-known, the Nord 2501 is in production for the Armée de l'Air. The combustion-heater nacelles are a novel and ingenious solution to the problem of stowing this equipment. Apart from obvious advantages of safety and accessibility, the wingtip nacelles may well act as quite useful endplates

harness, for the same reason, is unusual, consisting of a canvas back piece with two shoulder straps that clip on to a short chain attached to the front of the seat.

Particulars given by the firm are: span 11·10 m.; length 8·42 m.; height 2·40 m.; track 2·90 m.; wing area 18·81 sq. m.; tare weight 833 kg.; gross weight, aerobatic two-seater, 1,200 kg., three-seater 1,280 kg.; max. speed at sea-level 237 km.p.h.; cruising speed at 2,000 m. 202 km.p.h.; stalling speed 70 km.p.h.; climb to 2,000 m. 9 min. 20 sec.; service ceiling 5,500 m.; range 900 km., including allowances for warming up, take-off and climb.

The **Rey O1** is a clean twin-engined experimental monoplane built to test the Boyer flexible wing. It has a maximum speed of 325 km.p.h. and a loaded weight of 2,950 kg., so that it ought to be a fairly useful vehicle for gust experiments; but the further application of the idea seems to us unpractical.

Société Francaise de Constructions Aéronautiques had a stand at the Grand Palais on which were exhibited components of **Lignel** aircraft with the interesting Brodeau cork sandwich construction. This method, first shown in the 1938 Salon, never seems to get anywhere despite its interesting possibilities. At Le Bourget, this company also showed the **Vema 51**, which proved to be the Macchi 320 twin-engined six-seater, for which a licence is held. Although at first sight attractive, this wooden monoplane proved to have some doubtful features. The cabin was certainly spacious, with large windows, but the 250 h.p. Continental E-185 engines were very close to the fuselage and one would expect considerable engine and airscrew noise. Two-piece engine cowlings fitted well, but required a special key for the fasteners. The lever-action undercarriage relied on the retracting jack as the main drag member, upon which the loads must have been aggravated by the trail angle of the fixed part of the shock-absorber unit. Particulars and claimed performance are: span 13 m.; length 8·66 m.; wing area 21·13 sq. m.; tare weight 1,580 kg.; gross weight 2,340 kg.; max speed at sea-level 322 km.p.h.; cruising pseed at 2,000 m. 290 km.p.h.; stalling speed 108 km.p.h.; initial climb 5·7 m./sec.; ceiling 5,200 m.; full load range 1,130 km.

The three remaining nationalized companies did not have very much to show on their stands, although each is doing considerable practical work these days. The SNCA du Centre has been absorbed into the SNCA du Nord and the SNCA du Sud-Ouest since the last Salon.

The **SNCA du Nord** showed on its stand a mock-up of the fuselage of their **Nord 2501**, of which 160 are being built for the Armée de l'Air. At Le Bourget the aeroplane itself was shown. Generally similar to the Fairchild Packet in layout and size, it has two Bristol Hercules engines. Unlike the Packet, the fuselage has slightly convex sides, so that the skin is naturally stiffened. The manufacture and finish generally looked excellent. A curious feature was the installation of combustion heaters in nacelles at the wingtips and in the centre of the tail plane—an arrangement that certainly isolates the components in the event of fire and makes them easily accessible for maintenance and removal, FIG. 20.

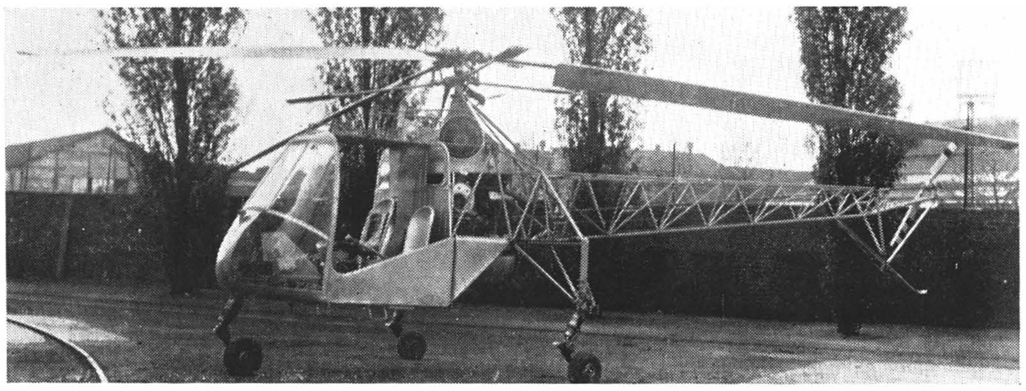


Fig. 22.—The SNCA du Sud-Est SE-3120 'agricultural machine' is a severely utilitarian helicopter. The large-area three-bladed rotor is controlled by servo rotors much like the Hiller

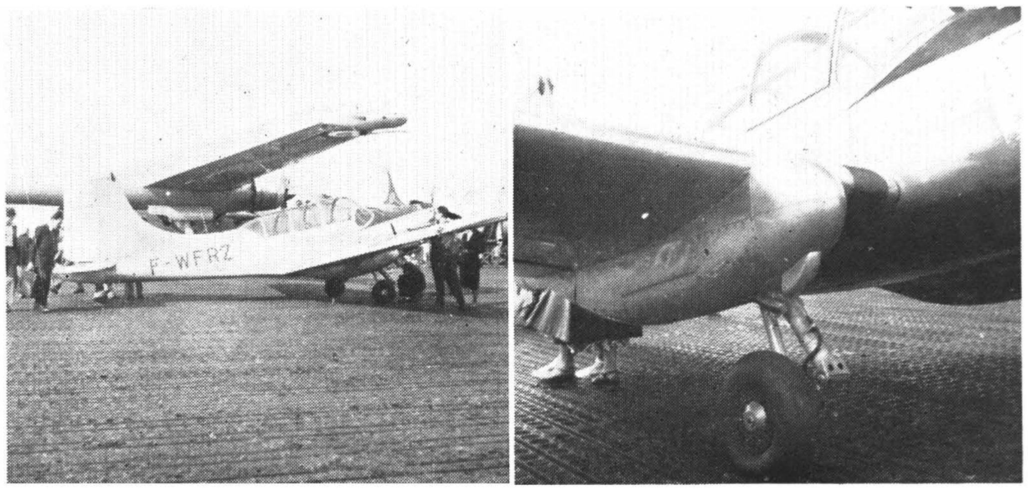


Fig. 21.—The Nord 2800 three-seater trainer was built to the same specification as the MS-733. It is a bulky, unwieldy looking aeroplane, such as one would not have expected from the works that produced the Norécrin

Also at Le Bourget was the **Nord 2800**, a three-seater trainer to the same specification as the Morane-Saulnier. Like that aeroplane it apparently suffered from the requirement for a large cockpit canopy and a semi-retractable landng gear, FIG. 21. In its design could be seen a resemblance to the Nord 1221 and the Norécrin, particularly in the wing and rear fuselage structure, which appeared to be common to the three types.* Details of the Nord 2800 were lacking at the time of going to press.

Models alone were shown on the stand of the **SNCA du Sud-Est,** but they were represented at Le Bourget by the first two production **Armagnacs.** This fine air liner has been described more than once in AIRCRAFT ENGINEERNG, so that there is nothing to add here.† We would, however, refer to a flight that we were fortunate enough to have in it. This confirmed the good impression we had when flying in the prototype last year—it is probably the quietest and most vibration-free piston-engined air liner today. Despite the cabin being full of ballast weights and very sparsely furnished the noise level was low and it was possible to balance light-alloy 5-franc pieces on the floor. Another convincing demonstration was the use of the reverse-pitch propellers to back the aeroplane out of a restricted parking area and to pull it up short on landing. The ground handling of the Armagnac struck us as being unusually good in all respects.

The newest product of the company, the **SE-3120** helicopter, FIG. 22, was only shown as a model. It is called, in the first instance, an 'agricultural machine'—although with characteristic Gallic ingenuity various other duties are also assigned to it. Nevertheless, it is first and foremost a simple and rugged, almost crude, aircraft. The earlier twin tail rotor layout has been abandoned in favour of the conventional single torque rotor and the three-bladed large-area main rotor is controlled by a servo rotor rather in the manner of the Hiller. Details of the rotor head were not available, but it was possible to note a 'hanging' stick with two dampers inserted in the linkage. Tension dashpot shock absorbers on the undercarriage are unusual. The engine is a Salmson 9 NH radial of 200 h.p. specially adapted as a helicopter unit.

Particulars of the SE-3120 are: rotor dia. 11·60 m.; length (nose to tail rotor) 10·40 m.; height 2·90 m.; tare weight 720 kg.; crop-dusting gear 45 kg.; fuel and oil 70 kg.; pilot 75 kg.; insecticide 240 kg.; gross weight 1,150 kg.; max. speed at sea level 130 km.p.h.; cruising speed 110 km.p.h. climb in forward flight 4 m./sec.; hovering ceiling 350 m.; normal ceiling 2,400 m.; endurance 1 hr. 30 mins.

One of the most interesting exhibits of the Salon, which was shown both statically and in flight, was the **SNCA du Sud-Ouest SO-1120 Aeriel III.** The development of these aircraft with jet tip drive has already been described in AIRCRAFT ENGINEERING and this latest achievement brings the long series of experiments, lasting over five years, to a logical and successful conclusion.‡

The interest in this latest version, of course, lies in the fact that fuel and air are delivered to the combustion chambers at the rotor tips by a pump and compressor, respectively, driven by a Turbomeca Artouste gas turbine of 275 h.p., FIG. 23. This power unit, with its negligible torque and vibration and its low weight can be mounted directly on a horizontal bulkhead at the middle of the fuselage, which also forms the top of the main fuel tank. The turbine exhaust is directed through a tailpipe lying inside the monocoque tail boom and ejected either straight aft or left and right by steel shutters that are interconnected with the rudder, FIG. 24. Induced by the exhaust gases cooling air is sucked through the space between the exhaust pipe and the tail boom skin from the engine compartment.

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* *See* 'Some Aspects of the French Aircraft Industry', by A. Charriou and 'The Nord Norecrin', by J. H. Stevens, AIRCRAFT ENGINEERING, Vol. XXI, April 1949, pp. 99-103 and 117-121 respectively.

† *See* 'The Aérosudest SE-2010 in Production', AIRCRAFT ENGINEERING, Vol. XIX, pp. 233-238, 265-271 and 'Progress with the Aérosudest Armagnac', Vol. XXII, pp. 318-322.

‡ *See* 'The Development of Jet Helicopters in France,' by André Charriou, AIRCRAFT ENGINEERING, Vol. XXII, October 1950, pp. 292-295.

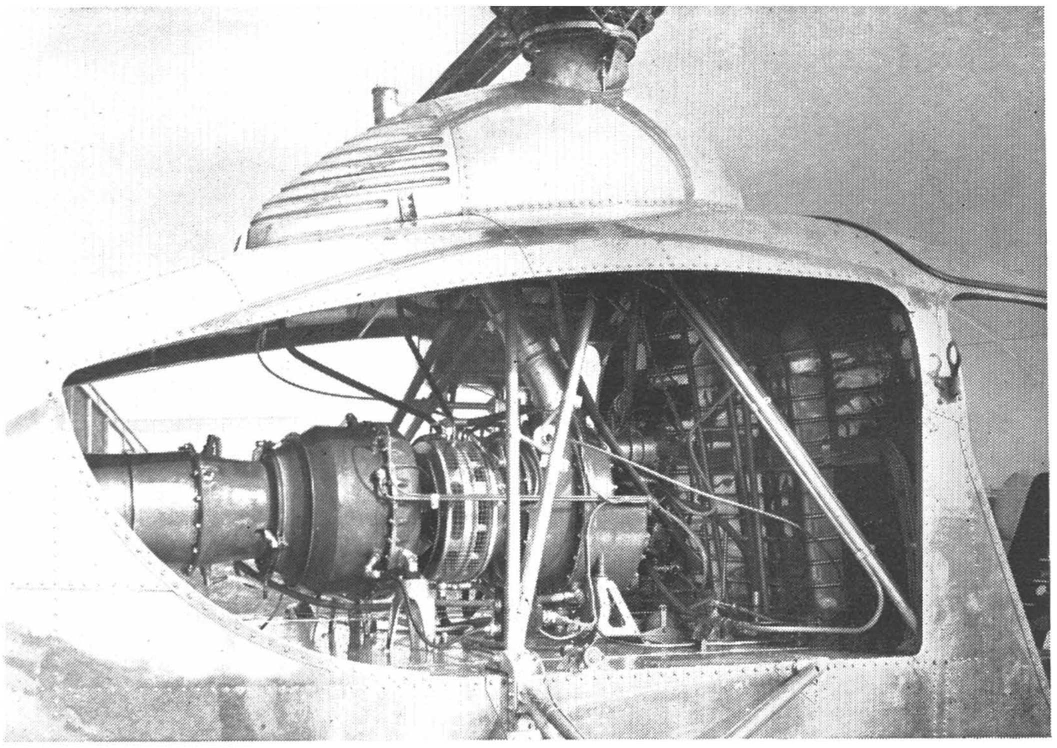

Fig. 23. —The SNCA du Sud-Ouest SO-1120 Ariel III has many interesting features, of which the engine installation is the most outstanding. Despite the essential simplicity of the power unit, there seem to be an unusual number of wandering pipes in the engine bay

Apart from its novelty, the SO-1120 impressed one by its straightforward design and good workmanship. The lay-out of its controls was generally similar to that of the Mark II illustrated in our previous article. There are, at present, two Mark IIIs, and they are largely experimental, although they are three-seaters.

In flight it was obviously a highly manoeuvrable aircraft, and it demonstrated a vertical climb to about 150 feet, as well as the usual helicopter evolutions and a fair turn of speed. One expected the jet-driven blades to be noisy, but the form of the noise was surprising. At a distance of two or three hundred yards it sounds exactly like a very elderly railway engine with a bad steam leak which, as the helicopter approaches, rises to a literally agonizing high-pitched whistle—so highly pitched that it must be almost at the top of the audible range. No doubt modification of the jet outlets will eventually eradicate this trouble. Until the noise is greatly reduced it must remain a disturbing factor when considering the type for civil use in built-up areas.

The SNCA du Sud-Ouest announce that they will apply their experience to the SO-1300, which will be a 'convertible' with fixed wings and airscrews in addition to the jet-driven rotor.

Data quoted for the SO-1120 are: rotor dia. 10·80 m.; tare weight 680 kg.; gross weight 1,250 kg.; fuel capacity (kerosene) 400 litres; max. speed 165 km.p.h.; cruising speed 135 km.p.h.; hovering ceiling 1,800 m.; service ceiling 4,400 m.; still air range 250 km.

Last of the aircraft alphabetically, but one of the most interesting of all was the **SIPA S-200**. This little side-by-side jet two-seater (FIG. 25) was only partially finished, work having started some ten weeks before the Salon. It is the work of M. Yves Gardan, a young designer who already has to his credit the very successful SIPA 901 and Minicab two-seaters, both of which have been ordered in quantity by the French authorities. Our photo shows the principal features of the design with its tail boom layout. Considerable thought has gone into making the structure as simple and cheap as possible despite the use of a laminar-flow aerofoil (N.A.C.A. 6 series) and double-slotted flaps.

The wing plan has a straight trailing edge and slight sweep on the leading edge. The spar is at right angles to the aircraft centreline (at rather more than 50 per cent of the chord) and is made from a simple plate with L-section extruded booms. The skin, 1·2 mm. thick and formed on a stretcher press, makes a torsion box with the spar, a false front spar running out as far as the tail booms. Since the aerofoil section is symmetrical the wing can be made in two halves and is joined by angle plates on the centreline. A minimum number of flanged-blank ribs with large lightening holes are used. Aft of the spar there is a light structure forming the shroud for the flaps and ailerons. By carrying the flap hinges on long brackets it is possible to keep the shroud gap constant with a purely radial motion. The large slot effect of the ailerons is reminiscent of the Supermarine 535. The ailerons, and other control surfaces have channel-section sheet metal spars, D-noses and self-supporting skins with channels impressed into them for stiffening. It was curious to note that, while the ailerons have a large slot, the rudders have close shrouds and the elevator is entirely unshrouded.

The tail booms are made from standard tubes and will be partially stabilized by a light-metal covered balsa fairing. One might expect some modification to this part of the design, which seems over-simple.

The nacelle is neat and simple, with the seats fitted into a cut-out in the leading edge. The hood is developed from a flat sheet and is mounted on a tubular frame that hinges forward. The Turbomeca Palas engine of 160 kg. thrust is mounted low in the rear fuselage with intakes under the wing roots. A large lift-up panel gives free access.

The undercarriage will have neat lever-action legs, the front one retracting backward and the others sideways into the bottom of the fuselage by hydraulic hand pump. The flaps, incidentally, will be mechanically operated. The machine shown had a single Y-type control column which seemed to us inadequate for a high-speed trainer. Fuel will be carried in the wings

Fig. 24.—The use of exhaust gas coupled with deflectors and with the rudder was used in the first Cierva helicopter. In the SO-1120 the extra volume of the turbine exhaust and the almost complete absence of torque make it a practical control system

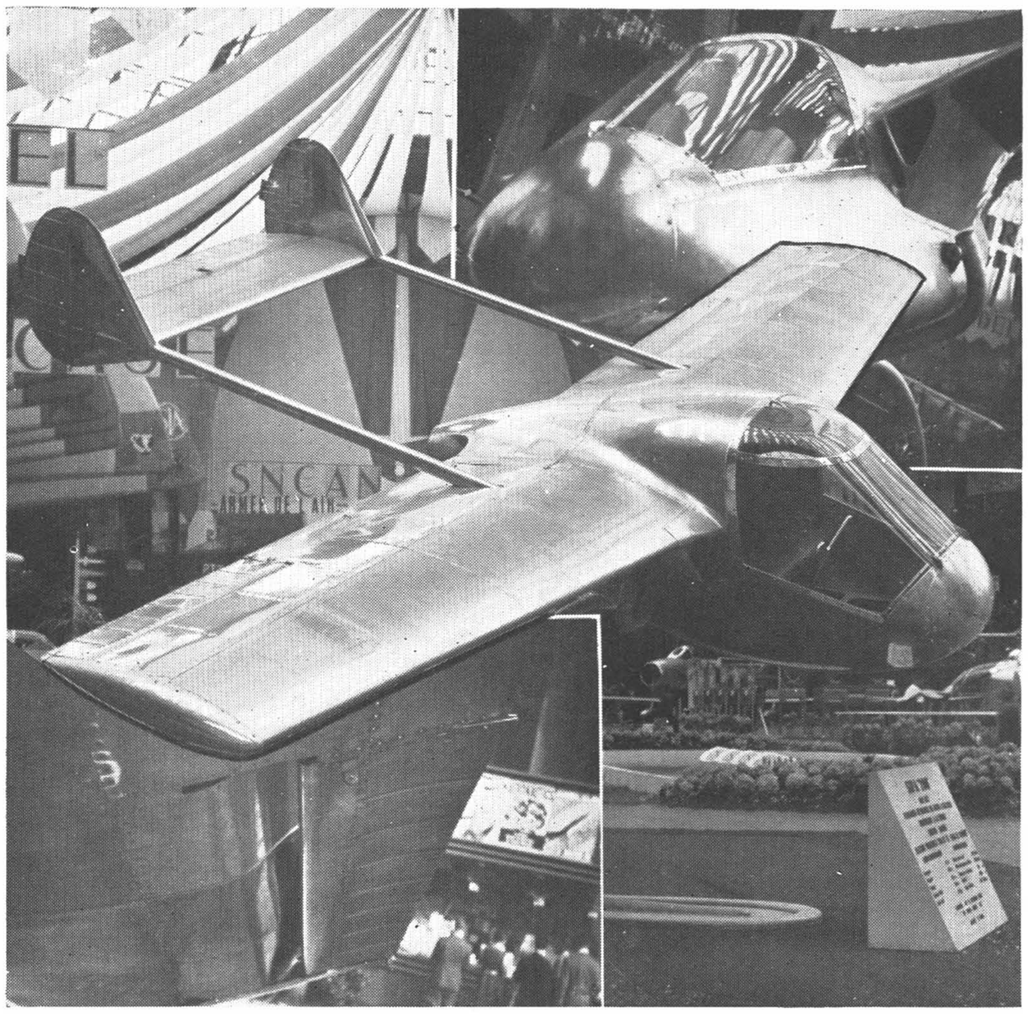

Fig. 25.—This composite block of the Sipa S-200 shows its main features clearly. The torsion-box section of the wing has only five ribs in each half span, since the pre-formed skin is comparatively thick. Note the large aileron slot, wing root intake with boundary-layer bleed, one-piece developed windscreen and beaded ribless control surfaces. The trailing edge, rear fuselage and tail booms were temporarily completed for the Salon

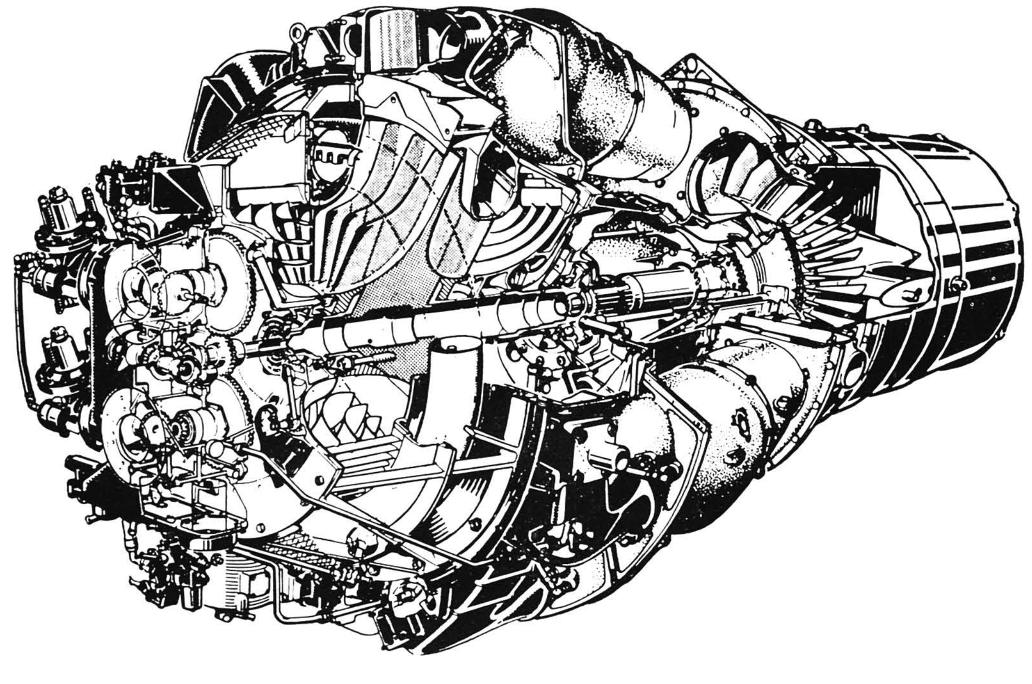

Fig. 26.—This Hispano Suiza drawing shows for the first time the interior of the Tay. A comparison with similar drawings of the Nene reveals a number of detail design changes

and fuselage and the aircraft is designed to be aerobatic with its fuselage load only.

The constructors hope to fly the S-200 in two or three months. The following provisional figures are given: span 7·2 m.; length 5.12 m.; height 1·78 m.; wing area 8·5 sq. m.; tare weight 289 kg.; fuel and oil 160 kg.; pilot, passenger and baggage 181 kg.; gross weight 630 kg.; max. speed 430 km.p.h.; cruising speed at 1,000 m. 380 km.p.h.; take-off run 180 m.; ceiling 8,000 m.; range 500-600 km.

Whether as a high-performance touring aeroplane or as an inexpensive jet trainer for giving jet experience to military pilots, the S-200 has a most promising future if it has anything like the outstanding flying qualities of its piston-engined predecessors.

ENGINES AT THE SALON

The engine side of the Salon was disappointing mainly because of the limited amount of information to be obtained about the more interesting exhibits. **Armstrong-Siddeley Motors** showed the **Sapphire** for the first time, but no details were released; **Bristol** displayed the **Centaurus-Ambassador** power plant and a beautifully-sectioned **Proteus**—which was in an impossible position to photograph—also for the first time. The **Avon** was a newcomer on the **Rolls-Royce** stand, but apart from being able to admire its compactness nothing more can be said about it.

The **Arsenal de l'Aéronautique** exhibited the **Ars 5501 'Engin Cible'**, a radio-controlled target with a development of the V-1 pulse-jet engine. Although the engine was shown in section, no drawings of it were available. The principal modification from the V-1 seems to be in the fuel delivery and in an arrangement of flame holders, behind the spring-steel intake valves, which separates the initial combustion. A thrust of 90 kg. is developed at 4,000 m., but details of consumption and engine life were not forthcoming. Also on this stand was a ram-jet unit which was supposed to have a thrust of 1,000 kg. and, as far as could be seen in its dark interior, two concentric U-section rings as flame holders instead of the series of cups used in the Sänger ducts. These units are to be fitted to the wing-tips of a VG-90 for flight test.

Hispano Suiza showed the **Tay** which is now in production, FIG. 26. The plump combustion chambers, packed closer than in the Nene, and the fat tail pipe gave a striking impression of power. Brief particulars of the engine were available: length overall 2,542 mm.; max. diam. 1,270 mm.; bare weight 895 kg.; thrust 2,850 kg.; consumption 1·06 kg./kg. thrust/hr. A **Nene** with an after-burner of Hispano Suiza design was also shown, FIG. 27. The bulk of these units make one realize something of the designer's problems when trying to install them. This version had pivoted orifice doors operated by a linkage from an electric motor. An auxiliary cooling muff was built round the rear part of the jet pipe.

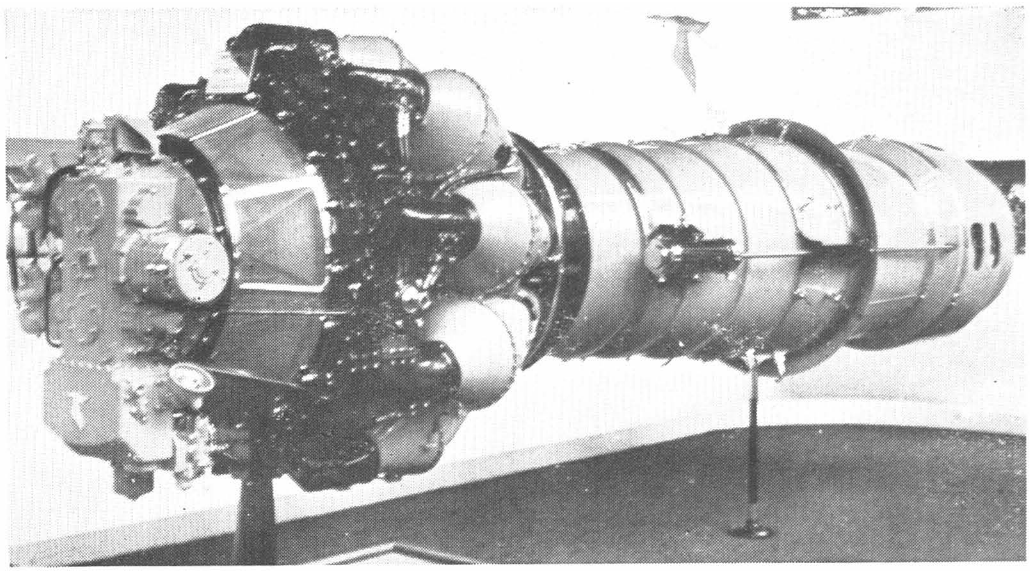

Fig. 27.—The Hispano Suiza built Nene fitted with an after-burner of their design. Note the operating motor for the variable outlet and the cooling-air muff

The **Société des Moteurs Henry Potez** showed various air-cooled engines of from four to twelve cylinders and 160 to 700 h.p., largely using similar components. These engines were exhibited at the previous Salon and were briefly described in our report upon it.* More interesting than the aero-engines were some auxiliary power units that appeared to be of neat and practical design.

The **Type 2D10** is a mobile generating set either for use on aircraft or on a ground trolley. It is a four-stroke, horizontally-opposed, air-cooled twin with governor-controlled constant r.p.m. and is mounted, with its generator, on a transportable tubular cradle. Ground level power is 5 h.p. at 4,500 r.p.m.; generator output 2,400 watts; weight complete 50 kg.

The **Type 2D2** is a more powerful unit intended mainly for engine starting. In addition to driving the generator, the motor operates a compressor and an auxiliary carburettor which supplies a fuel/air mixture for starting in place of the usual priming pump delivery. The twin-cylinder engine gives 6 h.p. at 4,500 r.p.m.; generator output is 2,400 watts; compressor max. compression 30 kg./sq. cm.; weight complete 50 kg.

The **Type 2H,** although mounted on a portable tubular bearer, is intended primarily as an airborne A.P.U. Because of this the four-stroke, twin-cylinder, air-cooled engine is cooled by a centrifugal fan and the cylinders are surrounded by aluminium baffles. Sea-level max. power 10 h.p.; continuous power 7 h.p. at 4,500 r.p.m.; bare weight 30 kg.; generator capacity 4 to 6 kw. Similar in conception to this is the **Type 4H**, FIG. 28, which is a larger unit with a four-cylinder engine. Sea-level max. power 18 h.p.; continuous power 12 h.p. at 4,500 r.p.m.; bare weight 38 kg.; generator capacity 6 to 10 kw.

Although it was interesting to note that the **Société des Moteurs Salmson** was still making its light radial engines, the outstanding exhibit on its stand was the **9NH** helicopter power plant of 200 h.p., FIG. 29. This is a nine-cylinder radial arranged to run on its back, but, unfortunately, details of the drive, hidden by the cooling-air shroud, were not to be had. Although direct injection is very popular in France just now for all sizes

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* *See* 'Engines of the XVIIIe Salon de l'Aeronautique' AIRCRAFT ENGINEERING, Vol. XXI, July 1949, pp. 204-208.

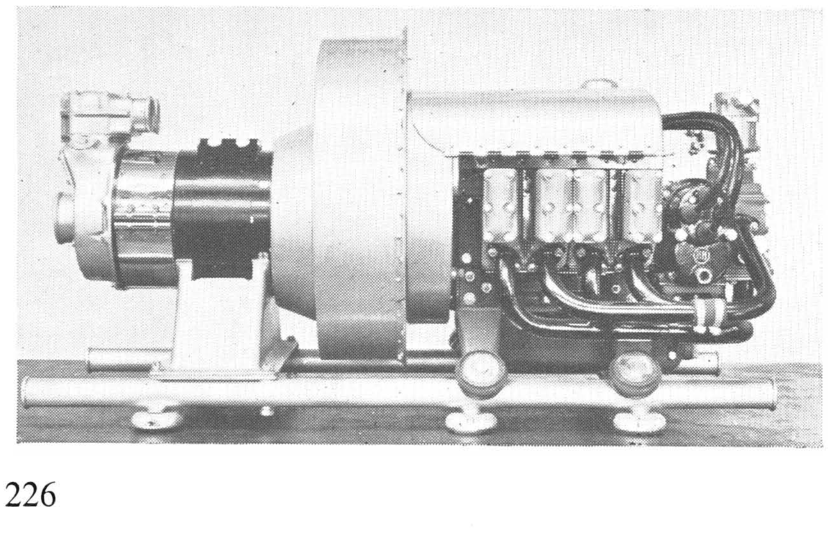

Fig. 28 (left).—The Potez Type 2H four-cylinder A.P.U. is typical of this firm's workmanlike designs and is mounted on a portable bearer

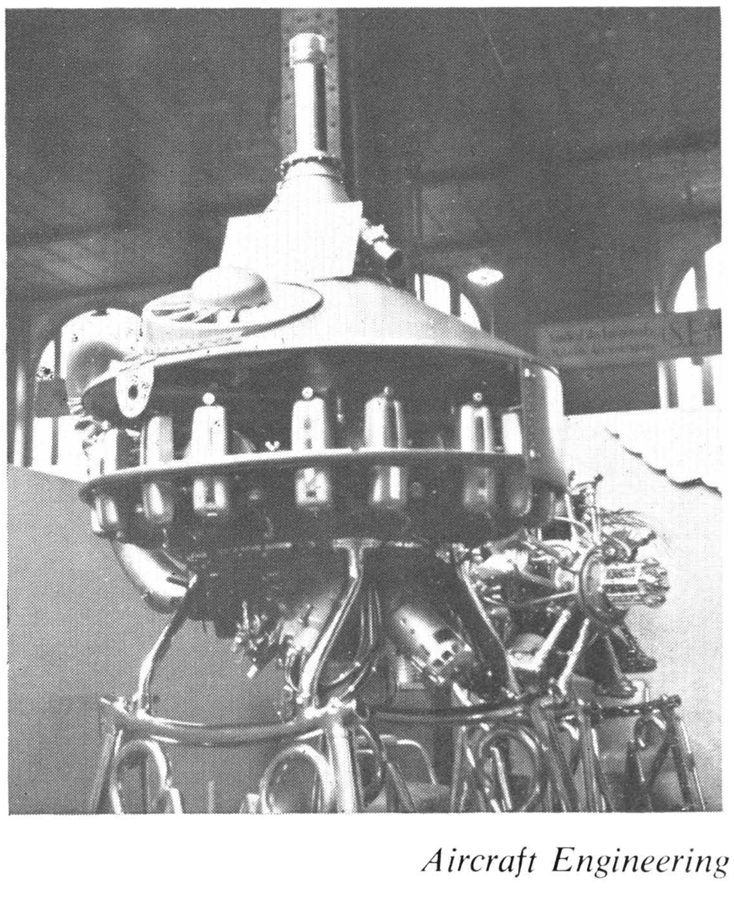

Fig. 29 (right).—The Salmson 9NH helicopter power plant appears to be a well thought out unit, but few details were available

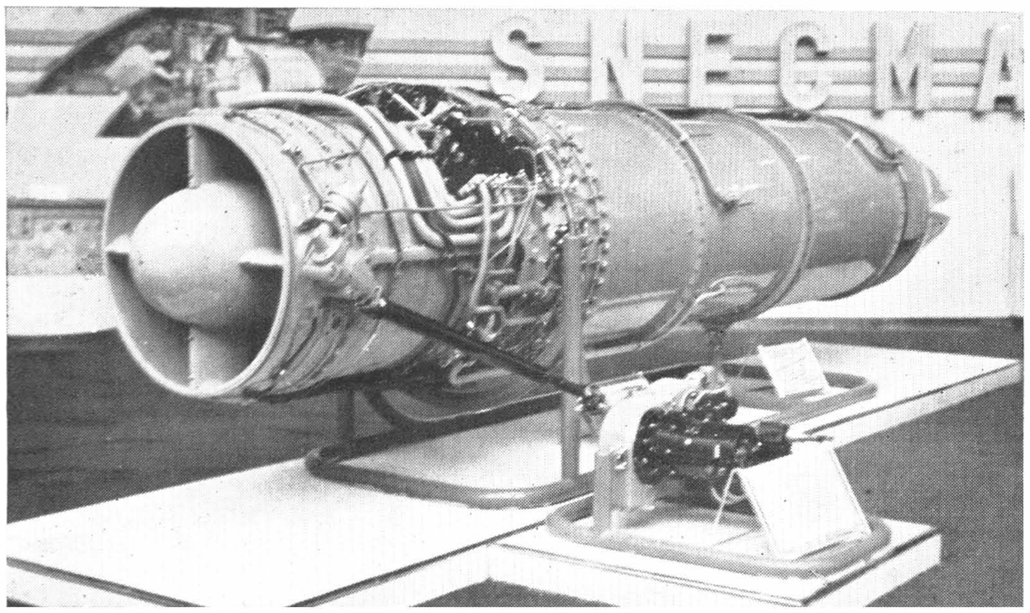

Fig. 30.—The SNECMA Atar 101B engine was shown with a mock up after-burner. The tightly-packed engine accessories and the auxiliary gearbox drive are the most attractive features of this engine

Fig. 31.—The SNECMA Escopette (Blunderbuss) in a triple unit under the wing of an Emouchet glider. The front mounting strut carries the fuel pipes and ignition leads, while the rear mounting is little more than a 'steady'. Discolouration of the main body and the recuperators shows where the parts run hot

of engine, this unit is fitted with a Zenith carburettor. Particulars of the engine are: bore 100 mm.; stroke 140 mm.; capacity 9·90 litres; bare weight, without accessories, 163 kg.; max. power 203 cv. at 2,150 r.p.m.; normal power 188 cv. at 2,050 r.p.m.; cruising consumption 245 gr./cv./hr.

The nationalized French engine company, **SNECMA**, showed the **Atar 101** engine complete with an afterburner—which we understand had not been run—and an auxiliary gearbox, FIG. 30. This engine was designed by H. Oestrich, who was formerly with B.M.W., and it is really a logical development of the 003. It was shown in 1949 and we published a cutaway drawing of it, so that it can scarcely be called new, yet it is only now undergoing flight trials in the tail of a Marauder. This is more or less typical of the rate of progress in the French jet field and makes one wonder when told that aeroplanes like the Mystère will be fitted with the Nene *or* the Atar. One Atar 101B engine completed its type test at 2,400 kg. static thrust in February this year and a later model is expected to deliver 2,600 kg.—while a 2,800 kg. thrust version is projected. Estimates of 3,300 kg. with water injection and 4,000 kg. with water injection and reheat are possible, but should be viewed in relation to past performances.

The neat **14XO**, fourteen-cylinder, air-cooled radial engine is said to have done well on test—one prototype ran 1,200 hours in one year. There seems, however, little use for an eight hundred horse-power engine with all the complications of a two-row radial. It is undoubtedly neat and compact, but by the time it could be got into production one feels that suitable propeller-turbines will be available. Furthermore, its lay-out would not be suitable for helicopters, where such a power category might well have a useful life of some years. In the light transport and military trainer classes, two other likely fields for this power, one feels that the multiplication of sparking plugs and valves, in particular, would militate against its choice.

For the purpose of record, we give the main characteristics: bore 122 mm.; stroke 116 mm.; capacity 19 litres; reduction geat ratio 1·2; compression ratio 6·8:1; take-off power 820 cv. at 3,100 r.p.m.; max. continuous power 680 cv. at 2,850 r.p.m. at 1,700 m.; recommended cruising power 410 cv. at 2,350 r.p.m. at 3,700 m., consumption 209 gr./cv./hr.

A very original valveless pulse-jet engine, the **Type 3340 Escopette**, was also shown by SNECMA, FIG. 31. The unit is interesting, but of rather dubious value because of its cumbersome dimensions—at least in its present form—and the devastating noise it produces. It is curious that although complete details of the construction were available, we could find no one who was able to explain the principle of the cycle. It seems probable that the tuning of the exhaust pulses forms a shock-wave that sucks in the next charge which is lit by the hot interior of the combustion chamber. If this is the principle, there seems little hope of a change in either the dimensions or the noise.

The photograph shows most of the details of the Escopette: the curved tube in front, called the *recuperator*; the air intake and the bright, unheated, fore part of the main body, called the *detector*; the tapering combustion chamber; long 'waist', and divergent exit nozzle. Inside the detector is a tube of the same diameter as the air intake, at the rear of which is an injector with eight radial nozzles, of 32/100 mm. diameter. The air space between the outer and inner tubes of the detector appears to be for cooling only, as there are small air inlets and outlets. The inner (or air delivery) tube is attached to a circular plate at its rear end which forms the front (or thrust) wall of the combustion chamber. This assembly has a shock-absorber spring so that some of the forward thrust of the pulses can be absorbed within the engine. For starting there is a small diameter sparking plug in the combustion chamber. The tail of the combustion chamber tapers sharply to the long 'waist' pipe, while the expansion nozzle has an angle of 3 deg. 30 min. Combustion chamber diameter is 120 mm., that of the nozzle 150 mm., while the overall length is 2·883 m. Mounting is at the front and the rear, the forward fitting being attached to the shock-absorber spring assembly inside the detector.

In the maker's literature there are numerous warnings indicating that the engine 'runs' very hot: bright, reflecting paint under the wing is recommended; ground running is restricted to one minute; the engine will re-light if fuel is turned on too soon after stopping.

The installation includes a battery and coil for starting and an air bottle for pressurizing the fuel system. The unit runs on petrol of any octane number, but not on kerosene.

When starting, fuel is delivered under pressure and a ground assistant presents a small air nozzle to the intake and injects air intermittently until

(*Concluded on p.* 245)

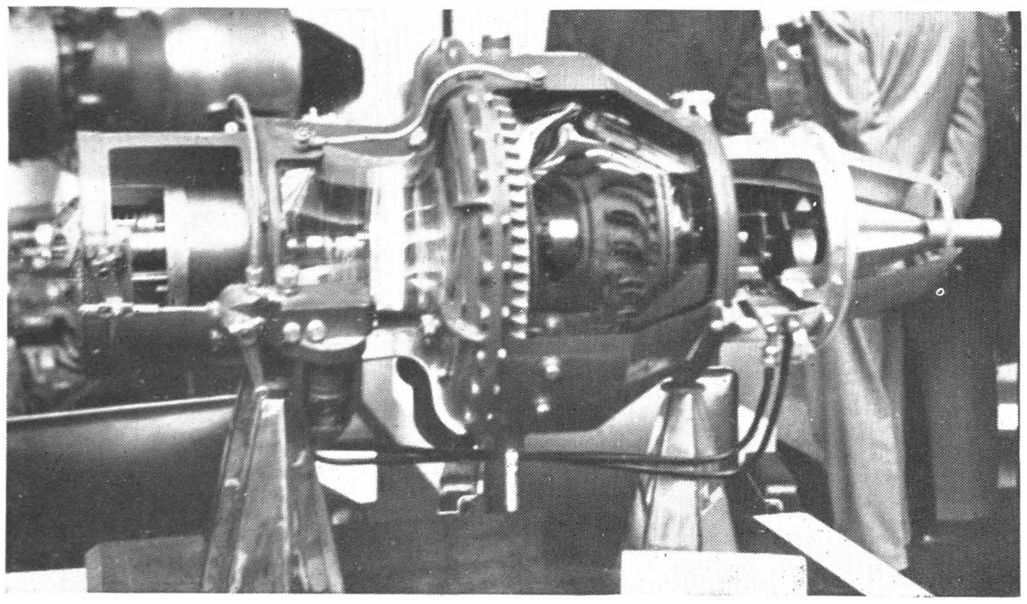

Fig. 32.—A sectioned Turbomeca Piméné. The fuel metering pump is mounted on the side of the fore body. In the interior of the main body the aerofoil-section blades are ducts for taking air from the outer part of the casing, through the rotary combustion chamber and into it from holes that perforate its inner skin

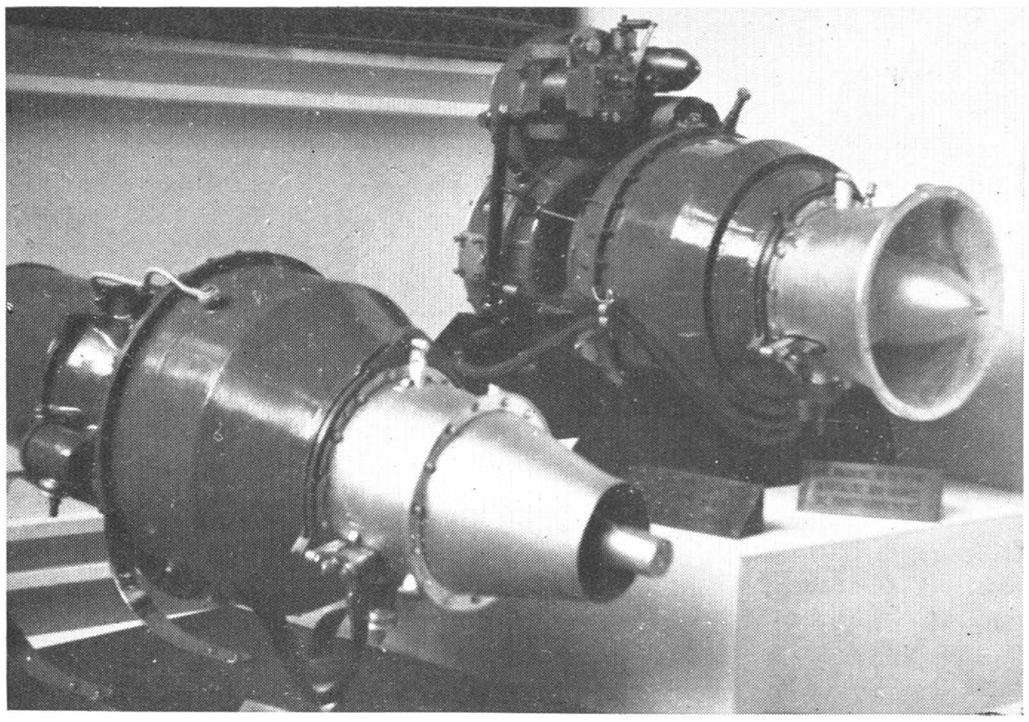

Fig. 33.—Two typical Turbomeca units: the Piméné pure-jet engine on the left and the Artouste air-compressor driving engine on the right, showing the intake duct shape

Fundamental Dynamics of Reaction-Powered Space Vehicles

A Paper Circulated for Written Discussion by the Institution of Mechanical Engineers

By L. N. Thompson, B.Sc.(Eng.), G.I.Mech.E.*

Introduction

With the great advances made during the last decade or so in the fields of rocket engineering, materials research, supersonic aerodynamics, electronics and nuclear physics, the problem of extra-terrestrial space flight has been removed from the realm of fantasy to the field of large-scale engineering problems. Rocket-powered reaction units occupy a leading position in the field of aeronautical research relating to high speeds, and the industrial application of atomic power is the object of many huge projects at present under development.

An examination of the problem of interplanetary travel therefore seems opportune.

Fundamentals

The problem of complete vehicular escape from a planet or planetary system is basically one of accelerating the space vehicle to a velocity at which its corresponding energy potential is sufficient to overcome permanently, without subsequent power expenditure, the retarding influence of the force fields peculiar to the planet or system. On attaining this minimum level of energy potential, and assuming that the propulsion units are then shut down, the vehicle will decelerate outwards from the field centre of the planet or system, zero vehicular velocity coinciding with infinity in the elementary mathematical theory. The practical interpretation of this is that the vehicle will continue to move outwards, without any further energy input, once this minimum energy potential has been built up. The velocity corresponding to this minimum potential is called the 'escape velocity' or 'velocity of liberation'.

Summary

This paper is an attempt to place in correct perspective the current considerable speculation regarding the problem of interplanetary travel.

The concept and importance of 'escape velocity' is dealt with first, and then the elementary mass-ratio equations for the motion of a space vehicle under various conditions are derived.

Available energy sources are considered next, the operational parameter being jet velocity. It is indicated that the maximum jet velocity conceivably attainable with chemical fuels is of the order of 20,000 ft. per sec. Nuclear fuels are dealt with and it is shown that, while energy potentials are very high, the problem of practical utilization is formidable. A thermodynamic type of atomic rocket motor employing an inert reaction mass to absorb the fission energy is postulated, and it is demonstrated that the heat transfer and materials requirements present a problem of the first magnitude.

The influence of propellent density on the performance characteristics of both chemical and atomic rockets is discussed, and it is shown that propellents giving high jet velocities may not necessarily be the best to use.

Orders of magnitude for the mass ratios required for various interplanetary flights are established, and it is indicated that only an atomic drive will render them small enough to be attainable in practice.

It is concluded that, unless nuclear energy can be suitably harnessed, economical space-travel will not be feasible.

Difficulty occasionally arises in grasping this concept of escape velocity and in appreciating its necessity and importance, as it is thought that if a space vehicle could be constrained to rise gradually from the surface of a planet and to continue slowly to do so into space, the process would eventually culminate in complete permanent escape from the planet's force field. This would only be so if the velocity of the vehicle at any given point reached, or exceeded, the corresponding value of escape velocity at that radius from the planet centre. If this condition were not satisfied, the vehicle would fall back once its repulsion energy-source were deactivated and its residual kinetic energy dissipated. On the other hand, once escape velocity is achieved, the vehicle will continue outwards regardless of whether or not the repulsion energy-source is in action. The inference of this with regard to fuel economy is of paramount importance. Continued operation of the energy-source beyond the escape point will only affect the value of the outward velocity.

The efficiency of the escape process is proportional to the acceleration at which it can be effected; the greater this acceleration, the smaller the distance which has to be travelled while reaching escape velocity. In consequence, less fuel or reaction mass need be expended in doing negative work against the force field in lifting the unused fuel or reaction mass to the escape point. A slowly accelerating space vehicle would therefore be uneconomical.

Escape Velocity

Analysis. From the inverse square law, $g \alpha 1/r^2$, that is, $gr^2 = \text{constant}$, and

$$g = G_o \frac{R_o^2}{r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

If a mass m_o accelerates out from the field centre of a spherically propagated force field, $m_o dV/dt = -m_o G_o R_o^2/r^2$ (the negative sign indicates that the accelerations are of opposite sense).

If both sides of this equation are multiplied by dr, and $dr/dt = V$ (the velocity at any instant), then $VdV = -G_o R_o^2 dr/r^2$. Integrating within limits gives $[V^2/2] = G_o R_o^2 [1/r]$.

As the vehicle is required to escape completely from the force field, the upper distance limit will be $r = \infty$ corresponding to $V = 0$. Hence

$$\Big[V^2/2\Big]_{V_e}^{o} = G_o R_o^2 \Big[1/r\Big]_{R_o}^{\infty} \text{ and}$$

$$V_e = \sqrt{(2G_o R_o)} \text{ at radius } R_o \quad \ldots\ldots\ldots \quad (2)$$

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BIBLIOGRAPHY

Ackeret, J., 1946 (April). Helvetica Physica Acta, p. 103, 'Zur Theorie Der Raketen.'

British Interplanetary Society, 1946 *et seq*. Journals and Bulletins.

Einstein, A., 1950. 'The Meaning of Relativity,' fourth edition (Methuen and Co. Ltd., London).

Sänger, E., 1950 (January). Weltraumfahrt (Gesellschaft für Weltraumforschung, Stuttgart).

Sutton, G. P., 1949. 'Rocket Propulsion Elements' (Wiley, New York).

Weyl, A. R., 1949. 'Guided Missiles' (Temple Press Ltd., London).

Notation

a = Maximum projected cross-sectional area of space vehicle
a_1 = Cross-sectional area of exhaust jet
$a_1 \Delta p$ = Pressure thrust
C = Universal gas constant, R/m_w
C_D = Drag coefficient
c = Velocity of light
D = Drag force due to air resistance
E = Theoretical energy equivalent of mass m_e
f = Constant acceleration from rest
G_o = Potential of gravitational field at radius R_o
g = Potential of gravitational field at radius r
J = Mechanical equivalent of heat
K = Defined by $\sqrt{(2gJ)}$
k = Defined by f/V_j
M = Total mass of any particular step of a multi-step rocket
$\mathcal{M}$ = Mach number
M_v = Momentum thrust
m = Structural mass corresponding to M
m_e = Mass of nuclear fuel
m_f = Final mass of vehicle
m_i = Initial mass of vehicle
m_o = Mass of vehicle at any instant
m_p = Mass of propellent per unit mass of nuclear fuel
m_s = Mass of satellite
m_w = Molecular weight of propellent
N = Number of steps in a multi-step rocket
n = Index in $pv^n = \text{constant}$
P = Density of propellent
R = Individual gas content
R_1 = Mass ratio
R_o = Radius of satellite, planet, etc.
R_{single} = Effective mass-ratio of single-step rocket
R_{step} = Effective mass-ratio of multi-step rocket
r = Any radius from field-centre
s = Radial displacement from reference datum
T = Thrust
H = Maximum heating-chamber temperature
t = Time corresponding to s
t_r = Period of revolution of satellite
V = Velocity of vehicle at any instant with respect to a fixed datum
V_1 = Velocity imparted to working fluid by a temperature drop ΔH
V_b = Velocity of jet at any instant with respect to a fixed datum
V_e = Escape velocity
V_f = Final velocity of vehicle with respect to a fixed datum
V_i = Initial velocity of vehicle with respect to a fixed datum
V_j = Jet velocity relative to vehicle
V_l = Velocity loss due to gravity, etc.
V_o = Orbital velocity of satellite
w = Total weight of products of complete combustion of unit weight of fuel
X = Calorific value of fuel
x = Specific propellent capacity of vehicle
y = Volumetric propellent capacity of vehicle
α = Efficiency of energy transfer between nuclear fuel and propellant
Δp = Pressure differential between exit of exhaust nozzle and surrounding medium
$\Delta \Theta$ = Temperature differential necessary to produce velocity V_1
η = Efficiency factor
ρ = Density of flight medium

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* **Assistant Engineer with Messrs Merz and McLellan, Consultants.**

Similarly, the escape velocity at any radius r is given by

$$(V_e)_r=\sqrt{\left(2G_o\frac{R_o^2}{r}\right)}=R_o\sqrt{\left(\frac{2G_o}{r}\right)} \qquad (3)$$

$\longrightarrow$

Alternatively, it may be considered that escape velocity is the velocity at which the vehicle possesses sufficient kinetic energy to enable it to escape completely from the gravitational field. At escape velocity V_e, the kinetic energy of the vehicle$=m_oV_e^2/2$. This is expended in doing work against the 'g' field, hence

$$m_o\frac{V_e^2}{2}=\int_{R_o}^{\infty} m_oG_o\frac{R_o^2}{r^2}\,dr,$$

dr being the infinitesimal moved through by the force.

This gives, as before,

$$V_e=\sqrt{(2G_oR_o)} \ldots\ldots\ldots\ldots \quad (2)$$

$\longrightarrow$

As the G_o and R_o values will be known, the theoretical escape velocity can, therefore, be calculated for any given planet, satellite, etc. In the foregoing, however, the limits $r=R_o$ and $V=V_e$ are taken to correspond. Obviously the velocity change from $V=0$ to $V=V_e$ cannot be instantaneous, as a finite acceleration must prevail in practice. The vehicle would, therefore, be accelerated from rest at R_o to practical escape velocity at some radius r, this modified escape velocity at r being given by Equation (3), where $(V_e)_r<(V_e)_{Ro}$, as $R_o/r<1$. The unknowns, $(V_e)_r$ and r, can be determined either graphically as shown in FIG. 1, or analytically as shown later.

r, miles	$(V_e)_r$ ft. per sec.	V, ft. per sec.		
		$1G_o$	100 ft. per sec. per sec.	$5G_o$
4,000	36,900	0	0	0
5,000	33,500	18,520	32,500	41,400
6,000	30,600	26,200	45,900	58,600
7,000	28,300	32,100	56,250	71,750
8,000	26,500			
9,000	25,000			
10,000	23,700			

$G_o=32{\cdot}2$ ft. per sec. per sec.
$3G_o\simeq100$ ft. per sec. per sec.
$R_o=4{,}000$ miles.

From the laws of motion, the velocity V attained by a vehicle after a linear distance s has been travelled at constant acceleration f from rest, is given by $V=\sqrt{(2fs)}$. Assuming a known constant acceleration value f, the velocity V of the vehicle at any radius r is therefore given by $V=\sqrt{[2f(r-R_o)]}$, and $V-r$ plots can consequently be obtained as in FIG. 1, which shows various velocity-distance curves, each drawn for one constant, finite value of f, plotted for a vehicle moving radially outwards from the Earth. The point of intersection of each of these curves with the escape velocity curve gives the radius at which escape velocity is attained for that particular acceleration.

The analytical solution is as follows, $(V_e)_r=R_o\sqrt{(2G_o/r)}$ and $V=\sqrt{[2f(r-R_o)]}$.

Squaring both and equating, to solve for r when $V=(V_e)_r$, $R_o^2 2G_o/r=2f(r-R_o)$.

Rearranging to obtain a quadratic in r gives $r^2-R_or-G_oR_o^2/f=0$.

Solving for r; $r=\{R_o\pm\sqrt{(R_o^2+4G_oR_o^2/f)}\}/2$.

The solution

$$r=\frac{R_o}{2}\left[1+\sqrt{1+4\frac{G_o}{f}}\right] \qquad (4)$$

is obtained when the inadmissible negative solution is neglected.

As G_o/f is dimensionless, the units used for radii and accelerations need not be the same.

The intersection of the velocity-distance curve, shown in FIG. 1, for a vehicle accelerating at 100 ft. per sec. per sec. (approximately $3G_o$) constant from rest, with the escape velocity curve, shows that escape velocity is attained at about $r=5{,}050$ miles. From Equation (4), $r=4{,}000/2\,[1+\sqrt{(1+4\times32{\cdot}2/100)}]=$about 5,056 miles. Here distances are in miles and accelerations in ft. per sec. per sec.

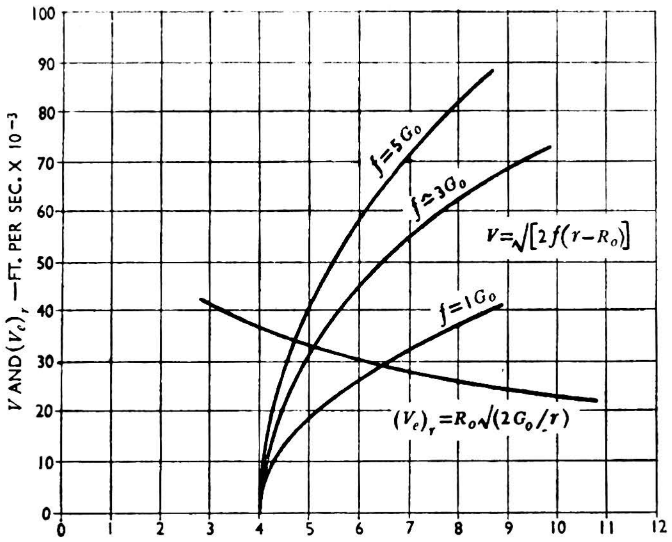

Fig. 1.—Escape velocity curve for the Earth

The analytical method is more convenient in general.

The foregoing analysis has assumed motion along a radius of the force field, that is, a radial linear trajectory. However, as the space vehicle at rest on the planet before take-off already possesses an energy potential proportional to the square of the surface speed of rotation of the planet about its own axis, it will obviously be advantageous to utilize this energy in aiding the vehicle to reach escape velocity. As only interplanetary travel inside a given equilibrated planetary system is being considered, the drift speed of the system and its components relative to other galactic systems need not be taken into consideration in energy potential calculations. The actual trajectory of departure, the optimum with respect to fuel economy, will therefore be a curve. The above preliminary analysis, assuming a simple radial trajectory, serves to demonstrate the nature of the escape problem, however.

Theory of Reaction Power Drives

It is reasonably well established that reaction-powered vehicles, such as rockets, afford the only practical means of achieving space travel at present.

A wholly self-contained reaction vehicle operates almost equally well in both a vacuum and under normal atmospheric conditions, operation under vacuum conditions being generally more efficient, however. The total drive impulse, or thrust T, in general consists of two components—a momentum thrust and a pressure thrust. That is, $T=M_v+a_1\Delta p$. When the exhaust gases are constrained to expand in the nozzle completely down to ambient pressure, the pressure thrust is zero, and the motor is said to be designed with 'optimum expansion ratio'. This condition gives the maximum thrust possible. The pressure thrust will obviously rise as the ambient pressure falls. The result is therefore a gradual increase in total thrust as this pressure falls. For example, the thrust of a V.2 type of rocket motor rises from about 56,000 lb. at sea-level to about 66,000 lb. at an altitude of 100,000 feet.

However, for true rockets the thrust developed must be at least of the same order of magnitude as the take-off mass involved. As this mass will be large (hundreds of tons) for interplanetary vehicles, the pressure thrust obtainable is therefore relatively negligible compared with the momentum thrust required. The thrust is therefore considered here as being due to momentum change only. When this assumption is made the following equations may be developed (Appendix I) for thrust T and equivalent vehicle acceleration dV/dt:

$$T=-\frac{dm_o}{dt}\cdot V_j \ldots\ldots\ldots\ldots \quad (5)$$

$$\frac{dV}{dt}=-\frac{1}{m_o}\cdot\frac{dm_o}{dt}\cdot V_j \ldots\ldots\ldots\ldots \quad (5a)$$

Velocity Equations for Space Vehicles

From Equation (5a),

$$dV/dt=-(1/m_o)(dm_o/dt)V_j;$$

then $\displaystyle\int_{V_i}^{V_f}\frac{dV}{dt}\cdot dt=-\int_{m_i}^{m_f}\frac{1}{m_o}\cdot\frac{dm_o}{dt}\cdot V_j\cdot dt$,

giving $\quad V_f-V_i=V_j\log_e(m_i/m_f)$

If the mass ratio m_i/m_f is denoted by R_1, $V_f-V_i=V_j\log_e R_1$ is obtained.

For a vehicle starting from rest, $V_i=0$, hence $V_f/V_j=\log_e R_1$, or

$$R_1=e^{V_f/V_j} \ldots\ldots\ldots\ldots \quad (6)$$

To attain a given escape potential, the velocity V_f must equal the corresponding escape velocity V_e.

Therefore, for a given jet velocity V_j, the minimum mass ratio required to achieve a given escape velocity V_e is calculated from

$$R_{\min}=e^{V_e/V_j} \ldots\ldots\ldots\ldots \quad (6a)$$

$\longrightarrow$

Equation (6a), however, is based on purely idealistic conditions, loss of thrust acceleration due to gravitational fields and air resistance being neglected entirely, as mentioned in Appendix I when obtaining Equation (5a) for dynamic operation. The practical equation of vehicle motion must therefore take the above acceleration losses into account as follows.

The equation of motion of a reaction vehicle accelerating radially out of a gravitational field, while under the influence of air resistance, may be written as

$$dV/dt=-(1/m_o)(dm_o/dt)V_j-G_oR_o^2/r^2-D/m_o.$$

The solution of this equation may be shown to be (Appendix II):

$$V_f=V_j\log_e\frac{m_i}{m_f}-G_o\left[\frac{\tfrac{1}{2}t}{1+(f/2R_o)t^2}+\sqrt{\left(\frac{R_o}{2f}\right)}\cdot\tan^{-1}\sqrt{\left(\frac{f}{2R_o}\right)}\cdot t\right]-\frac{\bar{C}_D\bar{a}\rho}{2}\cdot\frac{f^2}{m_i}\left[\frac{1}{k}e^{kt}\left(t^2-\frac{2t}{k}-\frac{2}{k^2}\right)-\frac{2}{k^3}\right] \ldots\ldots \quad (7)$$

From Equation (7) the practical mass-ratio of the vehicle can be calculated for conditions of uniform acceleration and radial linear trajectory.

Energy Sources

Energy for the propulsion of a reaction-powered space vehicle may be derived from two main sources; chemical fuels and nuclear fuels.

Energy Potentials Available. A parameter by which the potential of a given energy source can be conveniently measured, is the maximum jet velocity obtainable (directly or indirectly) from that source when its potential is transformed into the kinetic energy of a propulsion jet. The two energy sources mentioned above are therefore dealt with on this basis.

Chemical Fuels. For a fuel of calorific value X, the jet velocity V_j theoretically attainable may be calculated from the relationship $w/g\cdot V_j^2/2=JX$, that is

$$V_j=\sqrt{\left(2g\cdot\frac{JX}{w}\right)}=K\sqrt{\frac{X}{w}} \ldots\ldots \quad (8)$$

where $K=\sqrt{(2gJ)}$.

In practice, the above equation must be modified by a factor η, where η represents the percentage of the available heat X which can actually be transformed into kinetic energy. For example, when a nozzle for the expansion of a gas is considered, η represents the nozzle efficiency, the velocity equivalent of the heat fraction $(1-\eta)X$ being lost owing to frictional reheat and non-isentropic expansion. Endothermic reactions due to molecular dissociation also decrease the useful heat available, in some instances.

The practical conversion equation is therefore,

$$(V_j)_p = K\sqrt{\left(\eta \cdot \frac{X}{w}\right)} \quad \ldots\ldots\ldots\ldots\ldots \quad (8a)$$

with $\eta \leqslant$ 50-70 per cent in general.

Examples illustrating the method of calculating the jet velocity obtainable from a given chemical fuel are given in Appendix III.

TABLE I lists some of the available chemical fuels with their formulae, and gives the corresponding approximate theoretical jet velocities.

Hydrogen and gases generally have not been used much owing to the difficulty of storing any appreciable mass of them in the gaseous state, and research on the use of metallic fuels such as magnesium, and so on, has not yet reached the stage at which their operational use is practicable, although this field holds attractive possibilities and has received considerable attention, particularly from the German rocket research workers during the closing stages of the 1939-45 war.

TABLE I
JET VELOCITIES THEORETICALLY OBTAINABLE WITH AVAILABLE CHEMICAL FUELS

Fuel	Formula	V_j, ft. per sec.	V_j, miles per sec.
Carbon ...	C	13,500	2·56
Methane ...	CH_4	14,600	2·77
Petrol	C_8H_{18}	15,100	2·86
Hydrogen ...	H_2	17,000	3·22
Magnesium ...	Mg	18,400	3·49
Aluminium ...	Al	18,700	3·54
Beryllium ...	Be	23,000	4·35

In general, it can be stated with reasonable safety that about 21,000 ft. per sec. (4 miles per sec.) represents the maximum jet velocity which can ever be hoped for from chemical reactions.

Nuclear Fuels. As theorized by Einstein at the beginning of the twentieth century, mass and energy represent two different forms of the same fundamental and are therefore mutually convertible. This theory has since been proved to be factual by the advent of military and industrial atomic power.

From relativity theory, the theoretical energy equivalent E of a mass M_e may be calculated from the simple relationship

$$E = m_e c^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Equation (9) must also be modified by a transform-efficiency factor η in practice, where η represents the fraction of the mass m_e which can actually be transformed into energy. That is,

$$(E)_p = \eta m_e c^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9a)$$

This energy quantity $\eta m_e c^2$ represents the 'binding energy' of any given nucleus. If a nucleus can be constrained to split up (undergo fission), this binding energy appears as heat (primarily in the form of kinetic energy of the two heavy nuclei resulting from the fission of each heavier parent nucleus), light, and radiation (for example, gamma rays). A heavy unstable nucleus in its unified form has a greater mass than the mass total of the ligher particles prevailing after fission; this mass excess being transformed into released energy during fission in accordance with Einstein's equivalence relationship given above. This refers to 'breakdown' reactions or fissions, but 'build-up' reactions, such as hydrogen to helium, can liberate even greater amounts of energy (this is the operating principle of the hydrogen bomb). However, these build-up reactions are (at present) quite uncontrollable once initiated, and are therefore virtually useless from the engineering aspect.

The factor η is small for all nuclear fuels available at present. Some values are given in TABLE II.

An energy-release efficiency of about 1 per cent is therefore the maximum which can be assumed for calculation purposes. However, even with such a low efficiency, the total energy release from a given nuclear reaction is still very large indeed.

TABLE II
VALUES OF η FOR NUCLEAR FUELS

Nuclear fuel	Process	η
Uranium	Breakdown reaction	$\leqslant$0·1 per cent
Lithium	Breakdown reaction	$\leqslant$0·25 per cent
Hydrogen ...	Build-up reaction	$\leqslant$0·75 per cent

As it is neither desirable nor practicable to use the nuclear fuel as the actual propellent mass, it is therefore necessary to introduce an inert 'reaction mass' to absorb the energy evolved by the nuclear reaction and to serve as the ejected propellent. If the mass of propellent per unit mass of nuclear fuel be m_p, and the efficiency of the energy transfer between fuel and propellent be α; then, for unit mass of fuel, $\alpha\eta c^2 = \frac{1}{2} m_p \cdot V_j^2$, or

$$V_j = c\sqrt{\left(\frac{2\alpha\eta}{m_p}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (10)$$

$\longrightarrow$

As the numerical value of c in the above equation is 186,000 miles per sec., even with a value of η of less than 1 per cent, high values of V_j can still be attained theoretically. Before performing any calculations of theoretical jet velocities, however, it is advisable to consider the temperature potentials attendant on high velocities which are produced thermodynamically.

From the theory of elementary thermodynamics, the temperature differential or drop $\Delta\Theta$ necessary to impart a velocity V_1 to a given working fluid initially at rest and subsequently expanding, in accordance with the law $pv^n =$ constant, under conditions of isentropic frictionless eddy-free flow, may be shown to be given by the relationship, $V_1{}^2/2g = Rn/(n-1) \cdot \Delta\Theta$.

But R for any particular fluid is equal to the universal gas constant C divided by the molecular weight m_w of the fluid. Hence

$$V_1{}^2/2g = (C/m_w)[n/(n-1)].\Delta\Theta, \text{ or}$$

$$V_j = \sqrt{\left(\frac{C}{m_w} \cdot \frac{n}{n-1} \cdot 2g \cdot \Delta\Theta\right)} \quad \ldots\ldots\ldots \quad (11)$$

$\longrightarrow$

Equation (11) shows the jet velocity V_j to be primarily dependent on the initial temperature and the molecular weight of the working fluid. The initial temperature will, however, be strictly limited by material considerations, this being the same problem as that at present encountered in gas turbine development work. By using nickel alloys, some gas turbines today are able to operate at about 1,150 deg. K. but their working life is short owing to the rapid burn-out of even the best heat-resistant alloys under conditions of continuous exposure to high-temperature gases. The gas in the cylinder of a compression-ignition engine may reach peak temperatures of about 2,500 deg. K., but as this only occurs once during each cycle, the cylinder materials do not attain this temperature owing to thermal inertia and boundary layer insulation effects. The flame temperature of the propellent combinations (for example, ethyl alcohol or petrol plus liquid oxygen) used in present-day chemical rocket motors may exceed 3,000 deg. K. It is conceivable that an atomic rocket motor could be designed to operate at temperatures in the range 3,000-4,000 deg. K., as the period of operation would invariably be short and as a semi-expendable heating chamber (pile) design could possibly be adopted, together with methods such as sweat-cooling for reducing thermal shock. An upper temperature limit of 3,500 deg. K. is about the maximum which can be assumed for practical calculation purposes at present however.

Equation (11) is, therefore, evaluated for various working fluids, assuming that $\Delta\Theta =$ 3,500 deg. K. (For a given maximum chamber temperature Θ, $\Delta\Theta$ in general will be less than this, but for a reaction motor ejecting gases into a virtual vacuum at about Kelvin zero, the difference between Θ and $\Delta\Theta$ will be negligible.)

In general $V_j = \sqrt{[(1 \cdot 985 \times 1{,}400)/m_w \times n/(n-1) \times 64 \cdot 4 \times 3{,}500]} = 25{,}150\sqrt{[(1/m_w) \cdot n/(n-1)]}$ ft. per sec.

(Earth surface values have been taken for both C and g. As the value of g falls away with increasing radius from the field centre, the value of the universal gas constant will rise in direct proportion, leaving the value of V_j for a given fluid constant at all radii.)

If Equation (11) is evaluated for various working fluids, a table of jet velocities may be drawn up (TABLE III).

TABLE III shows that fluids of low molecular weight, such as hydrogen and helium, give the highest jet velocities. Molecular hydrogen gives the highest of all, and as this gas is highly combustible, it is conceivable that a further increase in jet velocity could be obtained by combusting the hydrogen after it had passed out from the initial system of nuclear heater and expansion nozzle. The system envisaged would be much the same as the 'after-burning' or 'reheat' system at present coming into use as a short-period booster for jet-propelled aircraft. For a space vehicle, this booster action could be used for take-off and immediate subsequent flight. Atomic hydrogen, with $m_w = 1$, would give even higher jet velocities than molecular hydrogen, but the handling and storage difficulties encountered with atomic hydrogen would render its use quite impracticable. Helium would have advantages from the safety point of view, being non-inflammable, and the advantages of ordinary water as a propellent, in the form of superheated steam, are obvious from both the economics and mass storage viewpoints. Dissociation effects at high temperatures might also tend to give higher jet velocities than those theoretically obtainable when using fluids of heavier molecular weight, such as water.

TABLE III
JET VELOCITIES THEORETICALLY OBTAINABLE BY ISENTROPIC EXPANSION FROM 3,500 DEG. K.

Working fluid	m_w	n* (value at normal temperatures)	V_j, ft. per sec.	V_j, miles per sec.
Hydrogen (molecular)	2	1·4	33,300	6·305
Helium	4	1·67	19,880	3·76
Water (superheated steam)	18	1·3	12,320	2·335
Nitrogen (molecular)	28	1·4	8,900	1·685
Air	28·92 (equivalent)	1·4	8,750	1·658

* This is the mean value taken over the expansion. It would decrease advantageously with increase in θ.

The mass of inert propellent associated with unit mass of nuclear fuel may now be calculated for various working fluids. From Equation (10) $m_p = 2\alpha\eta c^2/V_j{}^2$ (this is a dimensionless group).

Assuming $\alpha = 60$ per cent and $\eta = 0 \cdot 1$ per cent; on evaluation $m_p = 1{,}157 \times 10^{12} V_j{}^2$ is obtained (V_j in ft. per sec.).

The values of V_j given for various fluids in TABLE III enable the weight of fluid required per pound of nuclear fuel (TABLE IV) to be evaluated from the above equation.

From TABLE IV, for 1 lb. of nuclear fuel having an energy-release efficiency roughly equal to that of plutonium, an inert mass of 465 tons of molecular hydrogen would be required to absorb kinetically the energy produced by the complete fission of the fuel at 60 per cent heat transfer efficiency. Increasingly greater masses of the other working fluids would be required to achieve the same result.

The difficulties attendant on the utilization of atomic power for interplanetary propulsion should now be clear. The tremendous power potentials available from nuclear fission cannot

TABLE IV
FLUID REQUIRED PER POUND OF NUCLEAR FUEL

Working fluid	V_j, ft. per sec.	m_p	Fluid required per pound of nuclear fuel, tons
Hydrogen (molecular)	33,300	1,042,000	465
Helium	19,880	2,930,000	1,310
Water...	12,320	7,600,000	3,395
Nitrogen (molecular)	8,900	14,580,000	6,500
Air	8,750	15,100,000	6,750

be used to anything like their full extent owing to two main factors. These are:

(1) The temperature limitations of existing engineering materials.

(2) The practical difficulties of associating sufficient inert mass with the nuclear fuel to absorb the energy released by it during the fission process.

As an illustration, a vehicle of initial mass 750 tons is considered, taking off from the Earth at $3G_o$, and a jet velocity of 33,000 ft. per sec. is assumed. The equivalent thrust acceleration required will be $4G_o$ and the thrust 3,000 tons. From Equation (5), the corresponding propellent flow will be 6,550 lb. per sec., and hence the fuel consumption will be 0·0062 lb. per sec. The satisfactory heating of almost 3 tons of propellent per sec. up to about 3,500 deg. K. in a nuclear reactor assumed to be of the conventional honeycomb type (long passages of small individual cross-sectional area, offering high frictional resistance) is a materials and heat-transfer problem of the first magnitude. The required total heat-transfer rate is about 143 million B.Th.U. per sec., with a corresponding jet power of 202 million horse-power or 151,000 megawatts. (The V.2 rocket developed about 500,000 horse-power or 320 megawatts at the full thrust of about 30 tons.)

The foregoing analyses have assumed that the working fluid is preheated statically to the maximum permissible temperature and then expanded through a nozzle to obtain the velocity equivalent of this temperature; that is, all the heat energy is transferred to the fluid before expansion commences. It is possible, however, that additional heat could be progressively added to the fluid during expansion, thus causing further expansion and a consequent increase in jet velocity. The extent to which this could be carried out would be limited, however, by the considerable increase in specific volume of the fluid at the lower pressures, thus leading to excessive nozzle diameters. This same method of gradual heat addition, that is, tending towards isothermal operation, could possibly also be adopted to avoid high temperatures, such as 3,500 deg. K., in the initial heat-exchange stages of the atomic rocket motor.

It has also been assumed that the fission energy can be satisfactorily transferred to the working fluid at the required temperatures. The heat-exchange difficulties would be formidable, however, having regard to the energy levels and relative masses involved. The satisfactory disposal of the heat equivalent of the waste energy $(1-\alpha)\eta c^2$ which cannot be absorbed by the working fluid owing to inefficiency of heat transfer, would also present a great problem. Theoretically, a mechanical heat-exchange system could be avoided by causing the nuclear fuel to undergo fission when intimately mixed with the propellent mass, thus giving direct energy-transfer. The necessary conditions for the maintenance of a chain-reaction would be difficult to fulfil, however, as, owing to the great difference in the relative mass of fuel and propellent, the neutron wastage would almost certainly be high enough to render sustenance of the fission impossible. The economic and lethal aspects would also militate against the direct use of nuclear fuel in the propellent stream.

Unless some means other than the thermodynamic one can be found for utilizing atomic power, it therefore appears, as far as interplanetary propulsion is concerned, that nuclear fuels will be only two or three times better (with respect to the jet velocities developed) than the best chemical fuels available. If working fluids of low effective molecular weight in the gaseous form were used, it is conceivable that there could be developed a uranium- or plutonium-powered atomic rocket motor, operating at very high chamber temperatures, which could give jet velocities of up to about 50,000 ft. per sec. (about 10 miles per sec.). The prospects of any great improvement beyond this approximate value appear doubtful from the thermodynamic aspect.

The Influence of Propellent Density on Performance Characteristics

Considerable attention has been paid in the foregoing pages to the problem of attaining high jet velocities. However, the performance characteristics of the vehicle also depend to an appreciable extent on the density of the particular propellent used, as shown below.

If P is the density of propellent (for a bi-propellent chemical vehicle, this is the mean density of the fuel and oxidant when mixed in either their stoichiometric or 'best exhaust velocity' ratio, whichever is used in the particular instance) and y is the volumetric propellent capacity of the vehicle (that is, the tank storage space), then $m_i = mf + yP$, and

$$R_1 = \frac{m_i}{m_f} = \frac{m_f + yP}{m_f} = 1 + xP \quad \ldots\ldots\ldots\ldots \quad (12)$$

(x is y/m_f, the volumetric propellent capacity per unit final mass of vehicle, and can therefore be designated as the 'specific propellent capacity'). Hence from Equation (6),

$$V_f = V_j \log_e (1 + xP) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

From Equations (12) and (13), both R_1 and V_f depend on x and P. TABLE V gives the results of calculations based on these equations for single-step vehicles having the following design characteristics:

(1) Chemical Drive:
  (*a*) $P_{\text{mean}} = 60$ lb. per cu. ft. (75 per cent ethyl alcohol+oxygen); $V_j = 7{,}200$ ft. per sec.
  (*b*) $P_{\text{mean}} = 12$ lb. per cu. ft. (liquid hydrogen+liquid oxygen mixed in 'rich' ratio); $V_j = 12{,}000$ ft. per sec.

(2) Atomic Drive:
  (*c*) $P = 4 \cdot 5$ lb. per cu. ft. (liquid molecular hydrogen); $V_j = 33{,}000$ ft. per sec.
  (*d*) $P = 62 \cdot 5$ lb. per cu. ft. (water); $V_j = 12{,}300$ ft. per sec.

TABLE V shows that, judged on a basis of attainable vehicle velocity V_f, molecular hydrogen is a better propellent when used in an atomic rocket than when used in a chemical rocket. TABLE V also shows, however, that both for x values attainable at present, and for those likely to be attained in the immediate future, both chemical and atomic rockets using hydrogen have worse performance characteristics than a hydrocarbon chemical rocket, in spite of their higher jet velocities. An atomic rocket employing water as a working fluid has a performance superior to all others considered, even though it has a much lower jet velocity than the hydrogen atomic rocket.

It is shown that it is difficult to obtain high mass ratios using propellents of low density, and this disadvantage may more than cancel (in regard to attainable velocities) the advantage of the higher jet velocities obtainable in general from such propellents. Jet velocity is therefore not the only parameter to use.

Increase in specific propellent capacity x favours the atomic rocket in all instances, but x values of the order of one-fifth will be difficult to attain. The atomic rocket will also be at a disadvantage in this respect because of the inevitably high weights of reactor and shielding.

It may therefore be deduced that two desirable propellent characteristics are:

(*a*) a high density in the liquid form, and

(*b*) an ability to produce a high jet velocity, implying a low gaseous molecular weight.

These two characteristics may at first appear to be inherently opposed. However, the dissociation of relatively heavy molecules becomes pronounced at elevated temperatures. For example, for compounds such as water ($m_w = 18$), ammonia ($m_w = 17$) and methane ($m_w = 16$), dissociation becomes well advanced at temperatures around and over 3,500 deg. K., thus resulting in mean molecular weights much lower than would be obtained without dissociation. As almost unlimited amounts of energy (and hence temperature levels) would be available in an atomic rocket motor, the dissociation could be continued to an extent limited only by considerations of structural stability. The use of such compounds as propellents would therefore allow high jet velocities to be attained, while still maintaining a high liquid density in the storage tanks. The ideal combination of high jet velocity and high mass-ratio, and hence the optimum attainable velocity, would thus be achieved. An additional advantage would be that such compounds could also be stored in the liquid state much more easily than, say, hydrogen, which has a boiling point of about only 20 deg. K.

The error of judging propellents on a basis of attainable jet velocity only is well illustrated by the theoretical example of an electronic space-drive, that is, a form of linear accelerator discharging charged particles which have been accelerated by electromagnetic fields to speeds which are a considerable fraction of the velocity of light. Although high jet velocities can thus be attained, only a small amount of mass (propellent) could be accelerated by such a method, and hence the developed thrust would be low, much less than the dead weight of the vehicle. Such a drive would, therefore, only be of use to impart an infinitesimally small acceleration to a space vehicle already under conditions of field-free vacuum. These remarks apply equally well to 'radiation pressure' space-drives.

Some Flight Calculations

The foregoing formulae and results are now used to perform calculations concerning various extra-terrestrial flights.

(1) *Complete Escape from the Earth—Chemical Drive.* A radial trajectory of departure at a uniform acceleration of 100 ft. per sec. per sec. (approximately $3G_o$) is assumed.

From previous calculations, escape velocity is attained at $r = 5{,}056$ miles, that is, at approxi-

TABLE V
COMPARISON OF PROPELLENTS ON BASIS OF ATTAINABLE VELOCITY, V_f

Specific propellent capacity (*x*), cu. ft. per lb.	Mass ratio attainable (R_1)				Velocity attainable in field-free vacuum (*Vf*), ft. per sec.			
	Chemical drive		Atomic drive		Chemical drive		Atomic drive	
	(*a*)	(*b*)	(*c*)	(*d*)	(*a*)	(*b*)	(*c*)	(*d*)
	Ethyl alcohol	Hydrogen	Hydrogen	Water	Ethyl alcohol	Hydrogen	Hydrogen	Water
1/20*	4	1·6	1·225	4·125	9,980	5,640	6,700	17,450
1/10	7	2·2	1·45	7·25	14,000	9,460	12,240	24,350
1/5†	13	3·4	1·9	13·5	18,450	14,680	21,180	31,950

* This is approximately the value attained with existing large rockets which have been used operationally.
† This value will be difficult to attain.

mately 1,056 miles out from the surface of the Earth. The value of escape velocity at any radius r is given by Equation (3) hence:

$$(V_e)_{5056} = 4{,}000\sqrt{5{,}280}/\sqrt{5{,}056} \times \sqrt{64 \cdot 4}$$
$$= 32{,}800 \text{ ft. per sec.}$$

The time taken to attain this velocity is given by

$$t = \sqrt{(2s/f)} = \sqrt{(2 \times 1{,}056 \times 5{,}280/100)}$$
$$= 334 \text{ seconds.}$$

The velocity loss due to gravity may now be calculated from

$$(V_l)_g = G_o\left[\tfrac{1}{2}t\Big/\left(1 + \frac{ft^2}{2R_o}\right) + \sqrt{(R_o/2f)}\tan^{-1}\sqrt{(f/2R_o)}t\right]$$

(Appendix II), or

$$(V_l)_g = 32 \cdot 2\Big[(\tfrac{1}{2} \times 334)\Big/ 1 + \left(\frac{100}{2 \times 4{,}000 \times 5{,}280} \times 334^2\right) + \sqrt{((4{,}000 \times 5{,}280)/(2 \times 100))} \cdot \tan^{-1} \sqrt{[100/(2 \times 4{,}000 \times 5{,}280)]} \times 334\Big]$$
$$= 9{,}170 \text{ ft. per sec.}$$

The velocity loss due to air resistance is given by:

$$(V_l)_a = \frac{\bar{C}_D a \bar{\rho}}{2} \cdot \frac{f^2}{m_i}\left\{\frac{1}{k}e^{kt}\left(t^2 - \frac{2t}{k} + \frac{2}{k^2}\right) - \frac{2}{k^3}\right\}$$

(Appendix II)

It is assumed that air resistance will only be of importance during the first hundred miles of ascent. On this basis, the corresponding time is given by

$$t = \sqrt{(2s/f)} = \sqrt{(2 \times 100 \times 5{,}280/100)}$$
$$102 \cdot 8 \text{ seconds}$$

the velocity at the end of this time being 10,280 ft. per sec. (about 7,000 m.p.h.).

The value of $\bar{\rho}$ is taken to be equal to 0·04 lb. per cu. ft., that is, approximately half the air density at sea-level. This is a high value, but errs on the side of safety. The value to be assumed for $\bar{C}_D$ is also arbitrary, but 0·3 is taken for illustration purposes (for a sharp, taper-nosed cylinder, C_D is found to be 0·4 at $\mathcal{M} = 1$, dropping almost linearly to 0·2 at $\mathcal{M} = 4$). A projectile diameter of 6 ft. is assumed, giving $a = 28 \cdot 3$ sq. ft.

For the chemical power plant being considered, a value for V_j of 21,000 ft. per sec. is assumed (about the highest value possible, using beryllium fuel). Then $k = f/V_j = 1/210$.

The velocity loss may now be evaluated in terms of m_i,

$$(V_l)_a = (0 \cdot 3 \times 28 \cdot 3 \times 0 \cdot 04)/2 \,.\, 100^2/(m_i \times 2{,}240)$$
$$\{210e^{102,8/210}(102 \cdot 8^2 - 2 \times 102 \cdot 8 \times 210 + 2 \times 210^2) - 2 \times 210^3\}$$
$$= 249{,}000/m_i \text{ ft. per sec.}$$

where m_i is in tons weight.

Therefore, from Equation (7), $32{,}800 = 21{,}000 \log_e R_1 - 9{,}170 - 249{,}000/m_i$, and

$$21{,}000 \log_e m_i/m_f - 249{,}000/m_i - 41{,}970 = 0.$$

From the above equation, the value of m_i corresponding to any given value of m_f can be calculated. If m_f is assumed to be 2 tons, $m_i = 24 \cdot 2$ tons approximately, hence $R_1 = 12 \cdot 1$ approximately, and the velocity loss due to air resistance $= 249{,}000/24 \cdot 2 = 10{,}300$ ft. per sec.

The air resistance loss is therefore seen to be a considerable percentage (about 31 per cent) of the escape velocity. This is due mainly, however, to the small mass m_i considered (24·2 tons) and also to the fact that high values have been assigned to $\bar{C}_D$ and $\bar{\rho}$. True spaceships for interplanetary journeys would almost certainly have initial masses of from 750 tons upwards. Assuming this were so (and that the other values remained unaltered) the velocity loss would then be only 332 ft. per sec. (about 1 per cent) over the first 100 miles of ascent. This rough analysis shows that air resistance would present only a minor difficulty in large spaceship design.

As a comparison with the above calculations, the German A.4 rocket weapon (the V.2) attained a mass ratio of about 3·25/1 with a theoretical jet velocity of slightly 7,000 ft. per sec. (η was approximately 82 per cent). The above calculations have assumed the extremely high figure (for chemical fuels) of 21,000 ft. per sec., and even with this value a mass ratio of 12·1/1 is required for complete escape from the Earth. Hence, even with the considerable advances made in rocket engineering since the 1939-45 war (for example, the American 'Viking' rocket, which is expected eventually to attain altitudes of about 200 miles with a mass ratio of about 4·5/1), considerable development work will be required before chemically-powered vehicles can be constrained even to escape from the Earth's gravitational field, let alone attempt interplanetary flights.

TABLE VI
VELOCITY REQUIREMENTS FOR VARIOUS EXTRA-TERRESTRIAL FLIGHTS

Individual velocity requirements, ft. per sec.	Flight		
	Earth-Moon return, with Lunar landing	Earth-Mars return, with Martian landing	Earth-Venus return, with Venusian landing
Escape velocity for Earth ...	+32,800	+32,800	+32,800
Corresponding gravitational loss	+9,170	+9,170	+9,170
Corresponding air resistance loss (very approximate) ...	+1,000	+1,000	+1,000
Braking velocity required for landing on extra-terrestrial objective (same as surface value of escape velocity for this objective)	+7,550	+16,400	+34,200
Escape velocity (surface value) for extra-terrestrial objective	+7,550	+16,400	+34,200
Braking velocity required for landing back on Earth (equal to Earth-surface value of escape velocity)	+36,700	+36,700	+36,700
Air resistance braking effect when landing back on Earth (very approximate) ...	−20,000	−20,000	−20,000
Total velocity requirement, V_f	+75,170	+92,470	+128,070

(2) *Complete Escape from the Earth—Atomic Drive.* If the same general conditions as in (1) are assumed, the velocity loss due to air resistance must now be recalculated for the higher jet velocity V_j theoretically obtainable from an atomic rocket motor.

It is assumed that $V_j = 50{,}000$ ft. per sec. Then $k = f/V_j = 1/500$, therefore $V_l = 151{,}500/m_i$ ft. per sec. (m_i in tons weight).

Then, as before, $50{,}000 \log_e m_i/m_f - 151{,}500/m_i - 41{,}970 = 0$.

It is again assumed that $m_f = 2$ tons, so that $m_i = 7 \cdot 1$ tons approximately, hence $R_1 = 3 \cdot 55$ approximately, and the velocity loss due to air resistance $= 151{,}500/7 \cdot 1 = 21{,}370$ ft. per sec.

Rockets fitted with an efficient thermo-nuclear drive, and having mass ratios of the same order of magnitude as the V.2 would thus be capable of achieving complete escape from the Earth. However, the engineering difficulties involved render remote any hopes of such a drive becoming available in the near future.

(3) *Various Extra-terrestrial Flights.* As shown under 'Velocity Equations' and 'Multi-step Rockets', each of the velocity requirements, such as those due to escape velocity and to gravity and air resistance losses, which must be allowed for in calculations concerning a given interplanetary flight, can be calculated separately, and then summed-up to give a total 'characteristic velocity' requirement V_f, from which the required mass ratio can be calculated for a given jet velocity. The velocity requirements for various extra-terrestrial flights are tabulated and summated in TABLE VI, neglecting, however, those requirements due to extra-terrestrial gravitational losses. Also, for the Martian and Venusian flights, it is assumed that the air resistance braking effect when landing on these planets would be cancelled by the air resistance when taking off again.

From Equation (6), $R_1 = e^{V_f/V_j}$. If this equation is evaluated for the V_f values given in TABLE VI and for V_j values of

(*a*) 21,000 ft. per sec.—chemical drive, and
(*b*) 50,000 ft. per sec.—atomic drive,

the mass ratios required for the various flights, using the two above types of drive in turn, are found (TABLE VII). The results previously obtained have been included.

TABLE VII
MASS RATIOS REQUIRED FOR VARIOUS EXTRA-TERRESTRIAL FLIGHTS

Flight	Mass ratio	
	Chemical drive, $V_j = 21{,}000$ ft. per sec.	Atomic drive, $V_j = 50{,}000$ ft. per sec.
Earth escape—no return ...	12·1	3·55
Earth-Moon return, with Lunar landing	36·1	4·51
Earth-Mars return, with Martian landing	82	6·36
Earth-Venus return, with Venusian landing	458	13·1

TABLE VII clearly indicates that chemically-powered space rockets would require impossibly high mass ratios for any extra-terrestrial return flights, while on the other hand atomic-powered space rockets would be capable of achieving the same flights with relatively small mass ratios—small enough, indeed, to offer considerable hope for their achievement in due course.

The Earth-Moon return flight with Lunar landing, for example, would be the most elementary of all true space flights, but even this flight would require a mass ratio of 36·1/1 using chemical drive. A mass ratio such as this would be difficult to achieve in practice even with a multi-step rocket and high-density propellents. It is interesting that, using a V.2 type of power-plant giving a jet velocity of about 7,000 ft. per sec., a mass ratio of 29,240/1 would be required for the above flight—obviously an impossible figure, which demonstrates the inadequacy of present-day power-plants for interplanetary flight purposes. The tremendous reduction in mass ratio attendant on increasing the jet velocity from 7,000 to 21,000 ft. per sec. (this reduction being due to the exponential nature of the basic functions) illustrates the great importance of achieving high jet velocities. An atomic drive giving a jet velocity of 50,000 ft. per sec. would reduce the required mass ratio to 4·51/1—a reasonable result.

These remarks apply, with increased emphasis, to the other return flights.

Methods of Compensating for Low Jet Velocities

The foregoing calculations have shown that the low jet velocities obtainable from chemical rocket-fuels lead to impossibly high mass ratios for interplanetary flights. There are, however, methods by which this difficulty could be partially overcome, and these are now considered.

(1) *The Use of Multi-step Rockets.* A step-rocket, as the name implies, consists essentially of a number of single-step rockets coupled together in tandem, these 'steps' being fired consecutively. As each step reaches 'all-burnt', it is constrained to drop away from the main assembly, the next step then commencing to fire.

A step-rocket having N steps as shown in FIG. 2 is considered, and it is assumed that

(*a*) no velocity losses occur owing to time-lag, that is, the next stage commences firing immediately the previous one ceases, and
(*b*) there is constant jet velocity V_j.

If the total mass of any particular step be M, and the corresponding structural mass m, the propellent weight $= (M - m)$. The masses M and m for the Nth step include the payload. If the effective mass ratio of each step is denoted by R with the appropriate suffix, for the first step,

$$R_1=\frac{\sum_{1}^{N} M}{m_1+\sum_{2}^{N} M}=\frac{M_N+M(_{N-1})+\ldots M_1}{m_1+M_N+M(_{N-1})+\ldots M_2}$$

and for the second step,

$$R_2=\frac{\sum_{2}^{N} M}{m_2+\sum_{3}^{N} M}=\frac{M_N+M(_{N-1})+\ldots M_2}{m_2+M_N+M(_{N-1})\ \ldots\ M_3}$$

In general, for step *g*,

$$R_g=\frac{\sum_{g}^{N} M}{m_g+\sum_{g+1}^{N} M}$$

$$=\frac{M_N+M(_{N-1})+\ \ldots\ M_g}{m_g+M_N+M(_{N-1})+\ldots M(_{g+1})}$$

For the *N*th step, $R_N=M_N/m_N$.

The velocity increment V_f due to each step firing is given by $V_f=V_j \log_e R_{\text{effective}}$, and the total increment due to all steps having fired is given by $(V_f)_{\text{tot}}=V_j[\log_e R_1+\log_e R_2+\ \ldots\ \log_e R_g+\ \ldots\ \log_e R_N]$. Hence, $(V_f)_{\text{tot}}=V_j \log_e R_1 R_2 \ldots R_g \ldots R_N$.

The effective mass-ratio of the whole step-assembly is therefore

$$R_{\text{step}}=\frac{\sum_{1}^{N} M}{m_1+\sum_{2}^{N} M}\times\frac{\sum_{2}^{N} M}{m_2+\sum_{3}^{N} M}\ \ldots$$

$$\times\frac{\sum_{g}^{N} M}{m_g+\sum_{(g+1)}^{N} M}\ \ldots\times\frac{M_N}{m_N}$$

The effective mass-ratios R_1, R_2, R_g and R_N are not necessarily equal. If these are equal, however, then

$$R_{\text{step}}=\mathrm{R}^{N}_{\text{individual effective}}$$

If a single-step rocket having the same initial weight and structural weights as the foregoing step-rocket is now considered, the effective mass ratio for this single-step assembly will be

$$\frac{\sum_{1}^{N} M}{\sum_{1}^{N} m}=R_{\text{single}},\text{ and by inspection } R_{\text{step}}>R_{\text{single}}.$$

This result is due to the single-step rocket carrying all its structural mass throughout the entire firing period, while the step-rocket jettisons structural mass as soon as it becomes redundant (that is, when the step is 'all-burnt'). The step-rocket has thus progressively less mass to accelerate during its firing period, and a higher characteristic velocity can therefore be attained.

The multi-step rocket may therefore appear attractive at first, but a fuller design analysis shows that, for any appreciable payload and for any number of steps greater than about three, the take-off mass becomes prohibitively large. However, the method is useful for small payloads, and it is of interest that a two-stage rocket (V.2 first stage plus 'W.A.C. Corporal' second stage), fired at White Sands proving grounds, reached the greatest altitude yet recorded—about 240 miles.

(2) *The Use of Space-Stations or Artificial Satellites.* As escape velocity decreases with increasing radius from the field-centre, it will be of advantage if a space-flight can commence from a point situated considerably outside the Earth's atmosphere. This would involve the construction of an artificial satellite or 'space-station': this was the ultimate object of the American Earth Satellite Vehicle (E.S.V.) or 'Spaceships' programme initiated in about 1947.

A first requirement of such a project would be the development of an efficient short-range ferry-rocket capable of transferring materials from the Earth to the required point; the development of such a rocket may be hoped for in the reasonably near future, however.

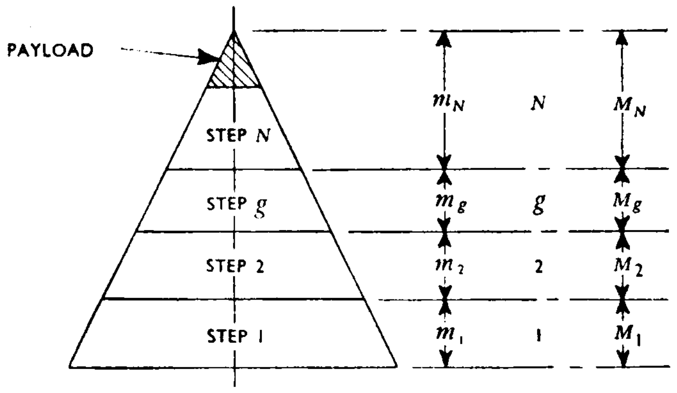

Fig. 2—Rocket with N steps

An artificial satellite is constrained to remain at a fixed distance from a field centre by causing it to move in an orbit around the centre with a velocity V_o such that centrifugal force balances gravitational attraction. That is, $m_s V_o^2/r= m_s G_o R_o^2/r^2$ (m_s=satellite mass). Therefore

$$V_o=R_o\sqrt{(G_o/r)}=R_o\sqrt{[G_o/(R_o+s)]}$$
$$=(\text{escape velocity})/\sqrt{2}.$$

The distance *s* may therefore be fixed as required, and the corresponding value of V_o calculated from this equation.

The energy required to place the satellite in its orbit consists of:

(*a*) the energy required to traverse the distance *s* against the gravitational field, and

(*b*) the energy required to create the orbital velocity V_o.

That is, total energy

$$=m_s\left[\int_{Ro}^{r} g.dr+\tfrac{1}{2}V_o^2\right]=m_s G_o R_o/2[(2r-R_o)/r],$$

or $m_s G_o R_o/2[(R_o+2s)/(R_o+s)]$.

The period of revolution t_r of the satellite is given by distance/velocity$=2\pi(R_o+s)/V_o= 2\pi/R_o.\sqrt{(R_o+s)^3}/\sqrt{G_o}$.

Space flights commencing from such a satellite would obviously have lower energy requirements than those commencing from the Earth's surface. The radiation difficulties associated with the exhaust of an atomic drive (that is, atmospheric pollution) would also be eliminated, as would air resistance losses.

Natural as well as artificial satellites could also be used for take-off points. For example, the use of the Moon as a commencing point for flights to Mars and Venus would reduce energy requirements considerably.

In general, it can be stated that the conception of the artificial satellite offers a promising field for investigation, being reasonably well within the scope of present-day engineering techniques.

Conclusions

The calculations given in this paper, while of a generalized nature, nevertheless indicate that interplanetary travel is unlikely to materialize for several decades at least. This estimate is about the most optimistic it is possible to make at present, as the calculations show that none of the chemical fuels now available possess energy potentials anything near sufficient to make space travel the economic proposition which it must become if it is ever to be of real value. It is possible that huge, unwieldy space vehicles using chemical fuels, capable of making the round Earth-Moon flight, could be constructed, but the cost and trouble of their construction would be so great that few of them could be built, and their value would be scientific only. Flights to the planets would be virtually impossible, even with the most powerful of future hypothetical chemical rocket-fuels such as colloidal beryllium with its possible ideal value of V_j of over 23,000 ft. per sec. (Sänger 1950).* The V_j value of 21,000 ft. per sec. assumed for chemical-drive calculation purposes is much greater than anything at present achieved, and even with this value the mass ratios required are extremely high. The optimum performance obtainable from chemical fuels has therefore been considered, and the results are still not good enough.

The inevitable conclusion is reached that unless energy potentials far higher than those associated with chemical fuels can be made usefully accessible, economical space travel cannot be realized. Fortunately, the energy released in nuclear reactions is more than ample for all the requirements of any interplanetary flight, and might even suffice for interstellar flights. However, even while this energy is definitely available, the problem of its practical utilization remains formidable. Some thermodynamic form of atomic rocket motor appears the only way at present available for harnessing nuclear energy for space-drive purposes, but the engineering difficulties involved in attaining a sufficiently high propellent/fuel ratio and heat-transfer efficiency are very great. Jet velocities such as the 50,000 ft. per sec. assumed in this paper may possibly be attained eventually with fluids of low gaseous molecular weight, but this value is nevertheless optimistic.

Devices such as step-rockets and space-stations offer promising fields for investigation, but do not greatly affect the basic problem. The only real solution is a rocket motor capable of giving very high jet velocities from fluids of high liquid density. It appears that only by the use of atomic power can this object be eventually attained, and even given such a rocket motor, the mass ratios required for major interplanetary flights will still remain large enough to require considerable ingenuity to achieve.

To sum up, it is reasonably safe to assert that suitable methods of using nuclear energy for interplanetary propulsion must be developed, or man must remain in effect permanently earth-bound.

APPENDIX I

Derivation of Thrust and Acceleration Equations

The mathematical expression for thrust developed is derived fundamentally from the Newtonian law of conservation of momentum, which states that following a reaction between two given bodies, the resultant momentum possessed by one body is equal and opposite to that possessed by the other body.

(*a*) *Static Operation.* A static reaction vehicle operating under steady conditions is considered first. If the vehicle has a total mass m_o at any time *t*, and a mass dm_o is discharged in time *dt*, then, as the vehicle is static, the reaction force or thrust *T* will be resisted by the restraints placed on the vehicle. If the jet velocity is V_j, the following equation results from application of the principle of conservation of momentum,

$T=-\frac{d}{dt}(dm_o V_j)$ (the negative sign is due to the convention used for velocities).

But V_j will be constant under steady operating conditions, hence

$$T=-\frac{dm_o}{dt}\cdot V_j \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The thrust *T* is a force which can be considered as the product of the mass m_o of the vehicle times the equivalent vehicle acceleration $\frac{dV_f}{dt}$, that is, $m_o\frac{dV}{dt}=-\frac{dm_o}{dt}V_j$, therefore

$$\frac{dV}{dt}=-\frac{1}{m_o}\cdot\frac{dm_o}{dt}\cdot V_j \ \ldots\ldots\ldots\ldots\ldots \quad (5a)$$

(*b*) *Dynamic Operation.* The more general example of a dynamic reaction vehicle is now considered.

It is assumed that the vehicle is operating in a field-free vacuum, that is, remote from any gravitational fields, so that both gravity and air resistance can be neglected initially.

Then $d/dt(m_o V)=-dm_o/dt\cdot V_b$, expanding, $m_o\cdot dV/dt+V\cdot dm_o/dt=-dm_o/dt\cdot V_b$, therefore $m_o\cdot dV/dt=-(dm_o/dt)\ (V+V_b)$. But, from rela-

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* An alphabetical list of references is given in the Bibliography.

tive velocity considerations, $V+V_b=V_j$, hence $m_o \cdot dV/dt = -dm_o/dt \cdot V_j$.

But $m_o \cdot dV/dt$ represents the mass times acceleration of the vehicle, and is therefore the force or thrust T acting on the vehicle. Therefore,

$$T = -\frac{dm_o}{dt} \cdot V_j \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

The vehicle acceleration is given by,

$$\frac{dV}{dt} = -\frac{1}{m_o} \cdot \frac{dm_o}{dt} \cdot V_j \ldots\ldots\ldots\ldots\ldots \quad (5a)$$

The negative signs in Equations (5) and (5*a*) do not signify negative thrust and deceleration, as dm_o/dt (the rate of discharge of propellent) is actually negative when referred to the vehicle mass m_o, being then a mass decrement. The product of the two negative signs therefore gives a positive expression for both thrust and acceleration.

Equations (5) and (5*a*) show that the thrust and the equivalent vehicle acceleration, under idealized conditions, are the same for both static and dynamic operation.

APPENDIX II

Solution of Practical Equation of Motion

The vehicle acceleration
$dV/dt = -1/m_o . dm_o/dt . V_j - G_o R_o^2/r^2 - D/m_o$
($D=$ drag force due to air resistance).

Integrating over the time range from zero to t,

$$\int_o^t \frac{dV}{dt} dt = -\int_o^t \frac{1}{m_o} \cdot \frac{dm_o}{dt} V_j dt - \int_o^t \frac{G_o R_o^2}{r^2} dt - \int_o^t \frac{D}{m_o} dt$$

Inserting corresponding limits,

$$\int_o^{V_f} dV = -\int_{m_i}^{m_f} \frac{dm_o}{m_o} V_j \int_o^t \frac{G_o R_o^2}{r^2} dt - \int_o^t \frac{D}{m_o} dt$$

Assuming motion from rest, and constant finite vehicular acceleration f, as under 'Escape Velocity', the value of r after a time t has elapsed is given by $r = R_o + ft^2/2$; from the laws of motion. For the gravitational integral,

$$I_G = \int_o^t \frac{G_o R_o^2}{r^2} dt = \int_o^t \frac{G_o R_o^2}{[R_o + ft^2/2]^2} dt$$

Integrating,

$$I_G = G_o \left[\frac{\frac{1}{2}t}{1 + ft^2/2R_o} + \sqrt{\left(\frac{R_o}{2f}\right)} \cdot \tan^{-1} \sqrt{\left(\frac{f}{2R_o}\right)} \cdot t \right]$$

A rigorous treatment of the drag force integral is not given. In any event, air resistance would only be of importance during the first hundred or so miles of ascent, after which a virtual vacuum would prevail. A general indication of the nature of the drag problem is given, however.

The drag coefficient C_D for a wingless vehicle is the sum of two separate coefficients, a friction coefficient dependent on air viscosity, and a form coefficient dependent on the physical geometry of the vehicle. At subsonic speeds C_D is dependent on the Reynolds number, and at supersonic speeds on the Mach number. Supersonic operation is assumed in the following analysis, being the more appropriate to high-speed rockets; that is, $C_D = f(M)$.

The drag D on the vehicle may be shown to have the form $D = C_D \cdot a\rho V^2/2$; the drag deceleration at any instant is therefore given by D/m_o, where $D/m_o = C_D a\rho/2 \cdot V^2/m_o$. Therefore,

$$\int_o^t \frac{D}{m_o} dt = \int_o^t C_D \frac{a\rho}{2} \frac{V^2}{m_o} dt$$

To render the mathematics of the above integration manageable, both C_D and ρ are assumed to have reasonable average values $\overline{C}_D$ and $\bar{\rho}$, so that these terms may be treated as constants in common with f.

Hence

$$I_D = \int_o^t \frac{D}{m_o} dt = Q \int_o^t \frac{V^2}{m_o} dt,$$

where $Q = \overline{C}_D a \bar{\rho}/2$.

To carry out the integration, it remains to express V^2 and m_o in terms of t and constants. From the laws of motion, $V^2 = f^2 t^2$. For m_o, an approximation only must suffice.

From Equation (6) $m_i = m_o e^{V/V_j}$. Hence $m_o = m_i e^{-V/V_j} = m_i e^{-\frac{ft}{V_j}}$, or $m_o = m_i e^{-kt}$, where $k = f/V_j$.

Therefore,

$$I_D = Q \int_o^t \frac{f^2 t^2}{m_i e^{-kt}} = \frac{Qf^2}{m_i} \int_o^t t^2 e^{kt} dt$$

Integrating,

$$I_D = \frac{\overline{C}_D a\rho}{2} \frac{f^2}{m_i} \left\{ \frac{1}{k} e^{kt} \left(t^2 - \frac{2t}{k} + \frac{2}{k^2} \right) - \frac{2}{k^3} \right\}$$

The final velocity of the space vehicle may therefore be written as

$$V_f = V_j \log_e \frac{m_i}{m_f} - G_o \left[\frac{\frac{1}{2}t}{1 + ft^2/2R_o} + \sqrt{\left(\frac{R_o}{2_j}\right)} \cdot \tan^{-1} \sqrt{\left(\frac{f}{2R_o}\right)} \cdot t \right] - \frac{\overline{C}_D a \bar{\rho}}{2} \frac{f^2}{m_i} \left[\frac{1}{k} e^{kt} \left(t^2 - \frac{2t}{k} + \frac{2}{k^2} \right) - \frac{2}{k^3} \right] \ldots\ldots\ldots\ldots \quad (7)$$

APPENDIX III

Examples Illustrating Method of Calculation of Jet Velocity Obtainable from a Given Chemical Fuel

(*a*) *Hydrogen*. A lower calorific value of 52,000 B.Th.U. per lb. is assumed. The combustion equation is

$$\begin{array}{lccc} & 2H_2 + & O_2 \longrightarrow & 2H_2O \\ & 4 & 32 & 36 \\ \text{or} & 1 & 8 & 9 \end{array}$$

(molecular and proportional weights being shown underneath).

The total weight of the products of complete combustion of 1 lb. of hydrogen is seen to be 9 lb.

From Equation (8),

$V_j = K\sqrt{(X/w)} = \sqrt{(2 \times 32 \cdot 2 \times 778)} \times \sqrt{(52{,}000/9)}$
$= 224 \times 76$
$= 17{,}000$ ft. per sec.

Assuming $\eta = 0 \cdot 6$, the practical value is
$(V_j)_p = \sqrt{0 \cdot 6} \times 17{,}000 = 13{,}180$ ft. per sec.

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(*b*) *Petrol*. A petrol of chemical formula C_8K_{18} and lower calorific value 18,200 B.Th.U. per lb. is assumed.

Working as before

$$\begin{array}{lcccc} & C_8H_{18} + & 12 \cdot 5O_2 \longrightarrow & 9H_2O + & 8CO_2 \\ & 130 & 400 & 162 & 368 \\ \text{or} & 1 & 3 \cdot 08 & 1 \cdot 246 & 2 \cdot 834 \end{array}$$

Therefore,

$V_j = 224\sqrt{(18{,}200/4 \cdot 08)} = 15{,}100$ ft. per sec.,

and

$(V_j)_p = \sqrt{0 \cdot 6} \times 15{,}100 = 11{,}700$ ft. per sec.

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PROFESSIONAL PUBLICATIONS

The Royal Aeronautical Society

JOURNAL (*Monthly*)

Vol. 55, No. 487, July 1951

Progress Towards Electrical Serviceability. R. H. Woodall and U. A. Higgs

Progress Towards Hydraulic Serviceability. R. H. Bound and H. G. Conway

Associazione Culturale Aeronautica (Italy)

RIVISTA AERONAUTICA (*Monthly*)

Vol. XXVII, No. 1, 1951

I. Radiosentieri. G. Ferrari

La virata Corretta stazionaria degli aeroplani azionati da turboreattori. A. Miele

L'Office National d'Etudes et de Recherches Aéronautiques (France)

LA RECHERCHE AERONAUTIQUE (*Alternate months*)

No. 21, May-June 1951

Le problème de l'onde de choc détachée pour les écoulements de révolution. H. Cabannes

Détermination rapide des trainées d'onde d'ailes en queue d'hirondelle. M. Bismut

Mesure de rendement des chambres de combustion de turboréacteur, par dosage de l'anhydride carbonique contenu dans les gaz d'échappement. J. Rappeneau

Utilisation des micropropulseurs pour l'étude de propergols. M. Barrère

Figures d'évaporation formées sur le cuivre chauffé dans le vide. P. A. Jacquet

Etude de la pénétration des résines dans les bois imprégnés par le tracé des isothermes d'adsorption et de désorption. P. Antzenberger

Les contraintes de cisaillement dans les barres ccurbes. R. Kappus

Institute of the Aeronautical Sciences (U.S.A.)

JOURNAL OF THE AERONAUTICAL SCIENCES (*Monthly*)

Vol. 18, No. 6, June 1951

Negative Camber Airfoils for Transonic Flight. T. B. Woersching

High-Efficiency Supersonic Diffusers. E. P. Neumann and F. Lustwerk

Dynamic Analysis of Aeroelastic Aircraft by the Transfer Function—Fourier Method. J. B. Rea

Buckling of Sandwich Cylinders under Axial Compression. F. K. Teichmann, C. T. Wary and G. Gerard

A Minimum Energy Solution and an Electrical Analogy for the Stress Distribution in Stiffened Shells. L. A. Goran

The Decay of Isotropic Temperature Fluctuations in an Isotropic Turbulence. S. Corrsin

Note on Bending of Thick Sandwich Plates. G. Gerard

AERONAUTICAL ENGINEERING REVIEW (*Monthly*)

Vol. 10, No. 6, June 1951

Closed-Circuit Oil Systems for Turbojet and Turbo-prop Engines. P. H. Schweitzer

Fatigue Problems in Transport Aircraft. W. T. Shuler

Desirable Longitudinal Flying Qualities for Helicopters. F. B. Gustafson

The Society of Automotive Engineers (U.S.A.)

SAE JOURNAL (*Monthly*)

Vol. 59, No. 6, June 1951

Summaries:

Lockheed Constitution Development Story. W. M. Hawkins and R. L. Thoren

Turbojet and Turboprop Engine Controls. F. C. Mock

The Institution of Production Engineers

JOURNAL (*Monthly*)

Vol. 30, No. 7, July 1951

The Teaching of Engineering Workshop Technology in Professional Courses. T. B. Worth

A Broader Conception of Productivity and its Measurement. F. G. S. English

The Toolroom—Its Relation to Production. H. W. Townsend

The Society of Licensed Aircraft Engineers

THE TECHNICAL INSTRUCTOR (*Monthly*)

Vol. VI, No. 6, June 1951

'Crashworthiness.' H. Smith

Electrical Services in Modern Air Liners. S. I. R. McIver

L'Association Française des Ingénieurs et Techniciens de l'Aéronautique (France)

TECHNIQUE ET SCIENCE AERONAUTIQUES (*Alternate Months*)

No. 2, 1951

Le laboratoire central de l'industrie des équipements aéronautiques. P. Mattei

De l'opportunité de multiplier les dispositifs de secours à bord des avions. R. Lucien

L'essai à temperature et pression variables des éléments et accessoires d'avion au laboratoire Chausson. M. Didier

Quelques essais sur les collages à haute résistance. Mlle Doussin

Manches à air de réacteur. M. Chevallier

PRODUCTION ENGINEERING ADMINISTRATION AND MANAGEMENT

The articles by Professor J. V. Connolly which were published serially in 1950 and early this year have now been published as an AIRCRAFT ENGINEERING Monograph, under the original title 'Production Engineering Administration and Management'. The book is obtainable from BUNHILL PUBLICATIONS LTD., 12 Bloomsbury Square, London, W.C.1, price 5*s*., postage 4*d*. extra.

The V-g Recorder Gust Investigation*

A Description of the Instrument and Explanation of its Uses Written Mainly for the Information of Pilots

By Squadron Leader C. V. G. Usher

A notable feature of the collaboration between this country and the U.S.A. since they became allies in World War II has been the exchange of ideas and the pooling of equipment, and one such item of equipment which has come our way is the V-g (velocity and *g*) recorder, an instrument originally devised by the National Advisory Committee for Aeronautics in America and sent to us during the war, which we improved and have used ever since to assist in our operational research.

This small recording instrument weighs a few pounds only and needs no attention in flight. (FIG. 1) It is fitted to selected service aircraft employed in their normal rôle, to civil air liners on regular routes, and occasionally, in order to collect special data, to aircraft such as the Meteors of the High-Speed Flight. *Its real value, however, lies in recording the normal air loads an aircraft encounters on routine duties,* and in this connexion, from the standpoint of obtaining truly representative results, it would be ideal if pilots were unaware of the presence of the recorder. This being impracticable pilots are asked to fly in their usual fashion and not to be influenced by the knowledge that a recorder is on hand—in fact, 'press on regardless' should be the motto!

Keeping Down Weight

All aircraft design is conditioned by the need to keep the airframe weight down to a minimum. While the aircraft structure must be strong enough to stand up to the job expected of it, extra structural weight means less fuel, ammunition, or bomb load; hence it is important that the weight be kept down to just what is needed, and no more. The increasing speeds of aircraft; the high altitude at which pressure cabin aircraft operate; the continual striving towards all-weather flying—all these and other aspects of aeronautical progress tend to increase still more the structure weight of the aircraft. The only way to tackle the problem is to adapt airframe structure more and more closely to the function which it has to perform, and that means collecting data to enable better estimates of airframe structural loads to be made. And that is where the V-g recorder comes in. Statistical measurement spread over many thousands of flying hours have to be made and analysed, and only when this has been done and records are available is it possible to account for the many variations experienced in research of this type. With such information available to them, the scientists are then in a position to say with reasonable accuracy what conditions of speed and acceleration aircraft have actually experienced in service—knowledge essential for efficient design.

Six Types

Since the war, considerable progress has been made in V-g recording, and this is a good opportunity to explain briefly the recording instrument itself and the technique of its use, and, finally, to give some idea of the results so far obtained in this rather unspectacular line of research—work in which many units have already co-operated, and in which no expensive plant or equipment has been used.

Centre of the work is the Royal Aircraft Establishment, Farnborough, which supplies the recorders—of which there are, in all, six types—on loan. Since the instrument is designed to record automatically—simultaneously with the airspeed—the accelerations normal to the flight path of the aircraft in flight, it is obvious that in a fighter-type aircraft, for instance, the call is naturally for a recorder capable of recording higher airspeeds and accelerations than, say, in a transport aircraft. It is for this reason that they are provided in a range of speeds and accelerations. Externally they are identical, the only difference being a slight variation of the internal mechanisms to produce a difference in the recording scales. All the recorders, incidentally, are interchangeable, and TABLE 1 shows the range available:

TABLE I

Type	Airspeed Range	Acceleration Range
A	40–400 m.p.h.	$-3g$ to $+6g$
B	70–500 m.p.h.	$-4g$ to $+8g$
C	70–600 m.p.h.	$-5g$ to $+12g$
D	40–300 m.p.h.	$-2g$ to $+4g$
E	40–300 m.p.h.	$-2g$ to $+6g$
F	40–400 m.p.h.	$-2g$ to $+4g$

Details of Operation

How, then, does the recorder do its job? Well, it has to show both acceleration and airspeed and for the purpose has an accelerometer to record the acceleration, and an airspeed capsule for recording the indicated airspeed at the time the acceleration is applied, both accelerometer and capsule being connected to a link system which moves a stylus bearing against a smoked-glass slide. The result is that on the slide the stylus draws a graph showing acceleration at a given indicated airspeed. The diagrammatic sketch of the recorder (not to scale) in FIG. 2 will help to make clear the principle of operation. It will be seen that the accelerometer itself consists of an inertia weight fastened to an arm pivoted at the right-hand side of the instrument, and that two coil springs (A) control the movement of this weight, while a slot at the end of the inertia arm engages on a peg in a second arm (B), which is pivoted and carries also, at its other end, the pivot for the stylus.

Suppose, because of an upward acceleration of the aircraft, the inertia weight moves downward relative to the case; the case, of course, will move with the aircraft, but the weight will try to follow the original path, the top spring being extended, the bottom spring compressed, and the inertia arm swinging downwards moving the arm (B) and the pivot of the stylus downwards with it. Thus a vertical line is drawn on the smoked-glass slide. A typical slide and two

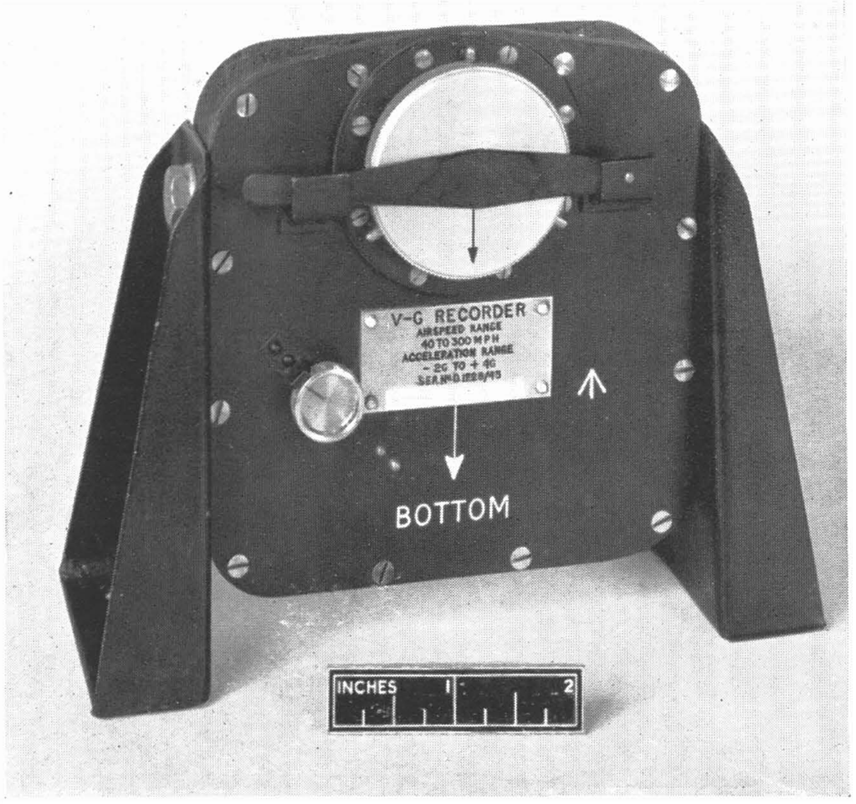

Fig. 1.—A V-g recorder

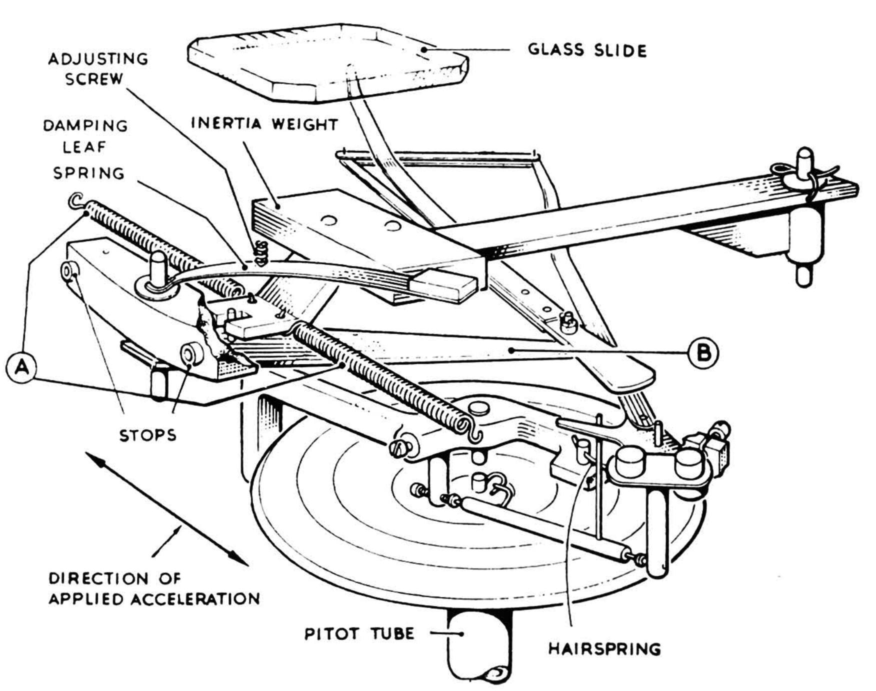

Fig. 2.—An insight into the general arrangement of a V-g recorder. It will be seen that the movement of the stylus is affected by accelerations and airspeed

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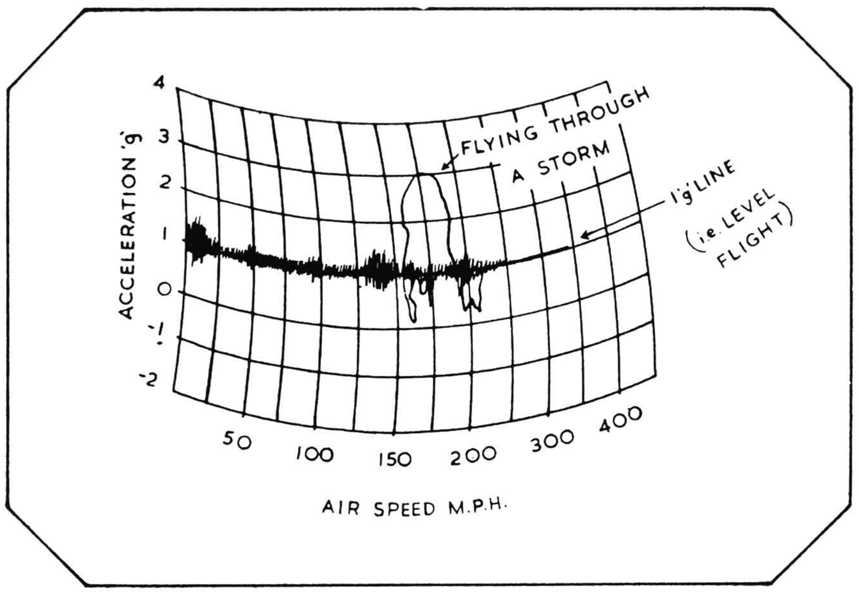
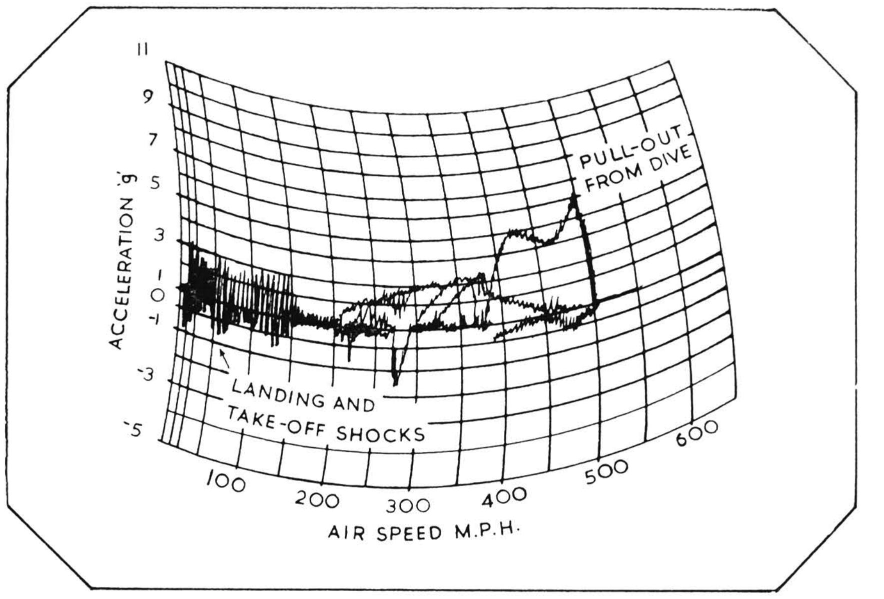


Slide from a Plymouth flying-boat which encountered a storm while flying on a regular route. Note that the highest acceleration recorded is +3g at 175 m.p.h.

Fig. 3.—Three examples of records obtained



Slide from a jet fighter. Here the highest acceleration recorded is +6g at 500 m.p.h., and the lowest, +2g at 220 m.p.h.

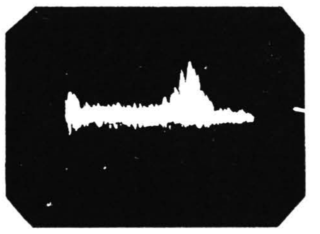
which have been enlarged for illustrative purposes (with their calibrated grids superimposed) are shown in FIG. 3.

It may be asked how the possibility of the inertia weight oscillating with engine or propeller vibrations is overcome. That is the purpose of the damping leaf spring on the pivot of the stylus arm (FIG. 2). Adjustment—a most important operation if the records are to be of any practical use—is accomplished by means of the adjusting screw. By the way, to prevent the stylus running off the smoked glass, the range of movements of the inertia weight is limited by two stops.

Consider next the airspeed capsule. This is connected to the pitot line from the pressure head, and as the inside of the case of the instrument is sealed and connected to the static pressure line, the capsule acts as a differential pressure gauge between pitot and static. (There is a safeguard for the pilot, who can isolate the instrument should he suspect that it is affecting his airspeed indicator readings). Figure 4 shows a representative installation circuit.

The recorders are sent out from the R.A.E., together with mounting bracket and a set of 12 slides in a transit case. They must be fitted on a rigid part of the aircraft structure as near as possible to the centre of gravity of the aircraft and perpendicular to the flight path; a typical installation is depicted in FIG. 5.

Because velocity and g recording is of particular importance in the development of transport aircraft, some such existing aircraft and all future ones of this type coming off the production line will have the necessary brackets and connexions for a V-g recorder already fitted.



Actual size of slide which had been previously blackened by smoking and which, after its removal from the V-g recorder, will be lacquered for protection

For the Record

Referring again to FIG. 3, it will be seen that, by studying the outline of the trail made by the stylus on the smoked-glass slide, it is possible to deduce the maximum acceleration occurring at any chosen speed, and also the maximum speed reached during the flying period covered by the slide. Although the landing and take-off shocks, too, can be clearly seen on the slides, they have been found too unreliable to be of use; consequently, the assessing of the record is confined to the 'in-flight' readings. As a matter of fact, the question of adapting a V-g recorder to record landing shocks is at present in hand, for such would, obviously, be of great assistance in undercarriage design.

Now since the V-g recorder acts continuously, in a few months enough experimental data can be obtained to represent many hundreds of hours' flying. Furthermore, a great improvement in the technique of handling these records has been made possible by an assessor (FIG. 6)—an instrument designed and built at the R.A.E., Farnborough—which, in a simple and quick operation, superimposes the calibrated graticule on the slide, and photographs the two for record purposes. During this process a magnified image of the slide is shown to the operator, which enables records to be given special examination or rejected outright if they are suspect for some reason, *e.g.*, vibration. The information read from this magnified image, together with the pilot's report accompanying the slides, is recorded on Hollerith punched cards, thereby facilitating greatly the sorting and computing operations, as well as providing an easy reference from which tabular summaries of the results can be drawn up.

Object in View

Let us leave the details of technique and examine the results obtained. So far, records representing in all some 70,000 hours on civil aircraft and 30,000 hours on service aircraft, have been collected and analysed. The aim of the research has been twofold:

> **To establish the adequacy of current assumptions on the severity of the gusts or 'bumps' for which aircraft need be designed.**
>
> **To determine the extent to which aircraft approach or exceed the limits of speed and manoeuvring acceleration for which they are designed, and, consequently, to change—if necessary—their specified flying limitations or, alternatively, to alter the design basis for future aircraft performing a like role.**

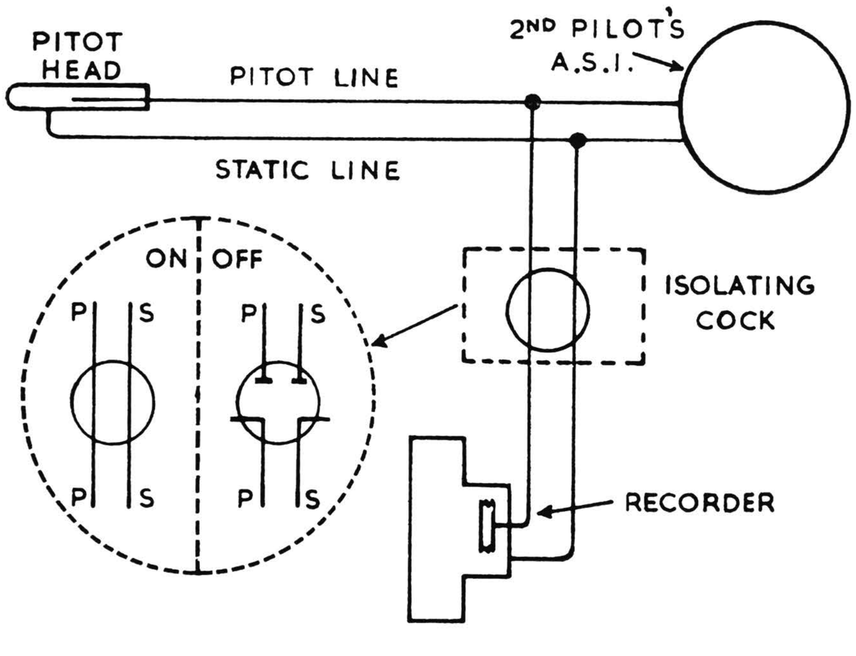


Fig. 4.—How the air lines connecting the V-g recorder are tapped into the aircraft's normal static and pressure lines. If necessary, the isolating cock can be operated by the pilot

Fig. 5.—A V-g recorder installed in a Sandringham flying-boat.

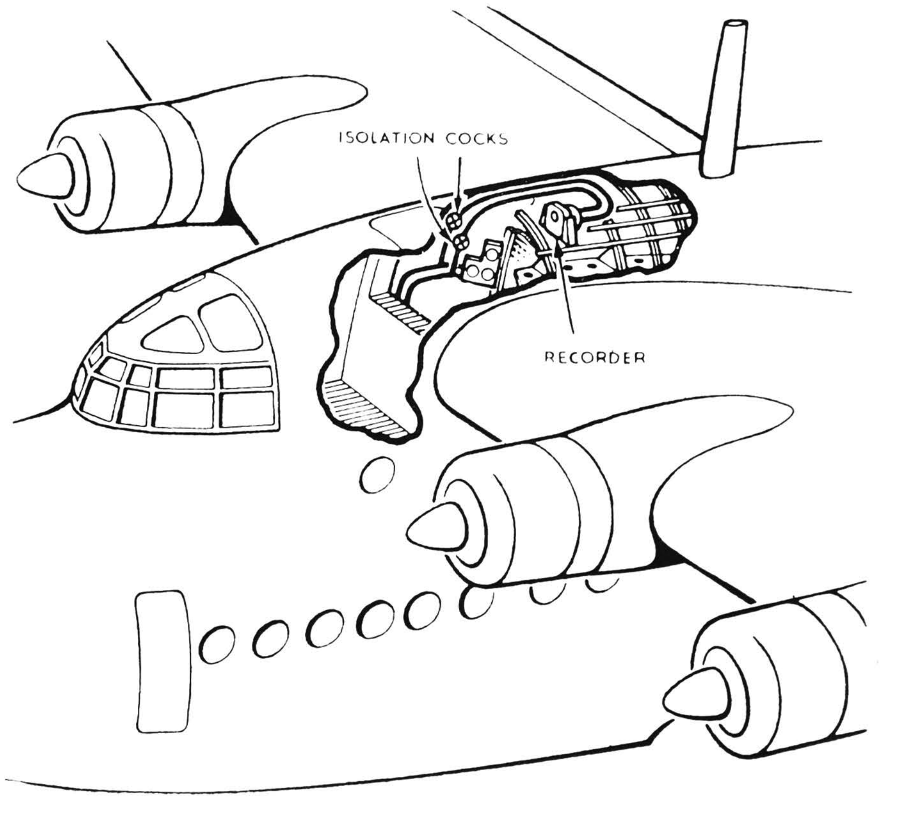


Fig. 6.—Assessing a V-g recorder slide in the assessor designed and built at the Royal Aircraft Establishment. The image of the small slide is magnified and projected on to the screen for the operator to read, after which he will photograph it for record purposes by simply pressing the camera press-button switch in his right hand. A batch of slides in transit case is on the table to the left

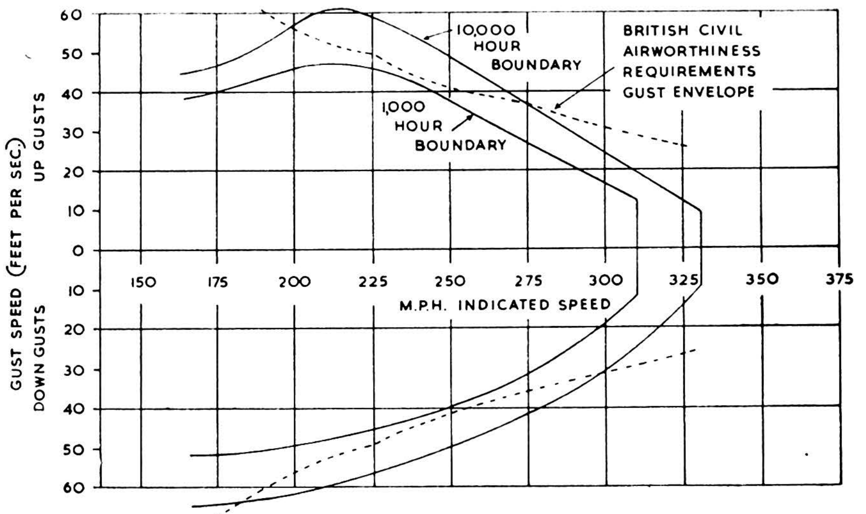


Fig. 7.—Gust and speed curves of gust conditions likely to be met in 1,000 and 10,000 hours' flying on the North Atlantic route from England to America

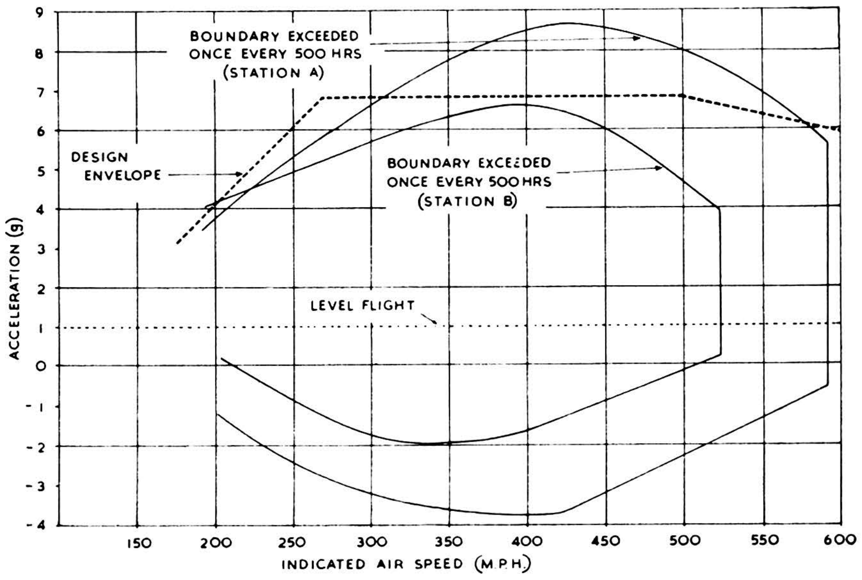


Fig. 8.—Acceleration and speed curves obtained from V-g recorders fitted to jet-engined aircraft of two different fighter stations. The higher g speeds reached at station A illustrate the wide variation of air loads which aircraft can experience even when employed in similar roles. Incidentally noting the nearing of the 9g mark by Station A, there is no cause for alarm. The aircraft in question have considerable reserve over the 'design envelope' shown

Recording Gusts

First, then, what about the effects of gusts? All who have flown have known the somewhat sickening 'bumps' which occur in gusty conditions, and the higher the speed of flight, the greater their severity. It is interesting that pilots, on switching from the old generation of fighters to Meteors and Vampires, should liken the gust effects at low altitudes to a series of jolts such as would be experienced if one drove a car downstairs or across a succession of pavement kerbs! Even so, the fighter aircraft structure is not usually worried by these gust loads, having been designed to withstand the more severe loads which the pilot himself often imposes during combat.

Transport and bomber aircraft are increasing their speeds rapidly, also, and on these types gust load conditions are often critical in the determination of wing strengths. If you have not done so already, fly in a Dakota or similar aircraft and watch how the mainplanes flex in bumpy conditions; then you will appreciate the value of the V-g recording. Not only do the gust load conditions affect the wing strengths, but also they may be all-important in the design for passenger comfort. That is why it is so necessary to know the size of the gusts which aircraft experience in their routine service life.

Most of the work has been done on civil passenger carrying aircraft, since these are less likely than the service aircraft to be subjected to deliberate manœuvres involving high acceleration. Hence records have been obtained on the main types of B.O.A.C aircraft on the Trans-Atlantic and Far Eastern services, and on the B.E.A.C. Vikings on the European routes. A typical example of the results obtained from about 3,500 hours' flying on the North Atlantic route by B.O.A.C. Constellation aircraft is given in FIG. 7; this shows the severity of gust conditions likely to be met in 1,000 hours' flying over the route from England to America.

Out of these studies by the R.A.E. has come support for the present practice of designing aircraft operating below 25,000 feet to withstand a 50 ft./sec. vertical gust at cruising speed and a 25 ft./sec gust at diving speed. Results so far are limited up to about 18,000 feet; the next stage is to conduct similar research at higher altitudes.

Exceeding the Limits

So much for the 'bumps'. Now let us follow the other line of approach—the extent to which service aircraft exceed the designed limits of speed and manœuvring acceleration. As soon as the re-equipping of squadrons with jet-engine fighters was well under way, to find out what speeds and accelerations the aircraft were subjected to by the average service pilot, a V-g recorder was installed in many cases. Records soon showed a tendency for high accelerations to be reached frequently at high speed—a state of affairs contrary to that which had been discovered in similar studies of piston-engine fighters. Further records from later marks, it is true, do not entirely bear this out, but manœuvring accelerations over the main cruising speed band are high; a fact illustrated in FIG. 8 where the design flight envelope of a jet fighter is compared with the accelerations reached in 500 flying hours by this type of aircraft at two different stations.

Sizing up the 'bumps'

To some extent, this exceeding of design safe limits is not unexpected, the specified design conditions for fighters having, in recent years, been deliberately reduced as part of the effort to increase their overall fighting efficiency by cutting down the airframe weight. Although there is still a reserve strength between the design safe limits and the ultimate strength of the aircraft, the situation must be watched carefully. That is why this line of research is so valuable, since it enables just such a watch to be kept on developments and shows the trend of things to come, so that preventive measures can, if necessary, be taken. That surely is a comforting thought, especially when it is realized that before V-g records were available, a trend might well go undetected until a number of serious airframe structural failures in the air drew attention to the changing conditions.

Future Developments

Quick to appreciate the practical worth of the results obtained with the V-g recorder, the scientific staff of the R.A.E. soon directed its efforts towards developing instruments which would enable similar studies to be made of other conditions of operation having a bearing on airframe structural design.

An automatic controlling device, for instance, has been devised to bring the V-g recorder into operation only above a predetermined height; a refinement of great assistance in the determination of air loads at varying altitudes, which hitherto was not possible. Does it seem unnecessary that the recorder should have an automatic controlling device? Not when the aim is to 'fit and forget' these recording instruments in aircraft—until such time, anyway, as the required amount of flying has been done. Again, it cannot be too strongly stressed that—if the records are to be of value—the presence of the instrument should in no way influence the pilot's manner of flying.

Another instrument being developed will enable the simultaneous recording of speed, acceleration, control surface angles, altitude, and so on. Moreover, considerable progress has been made with a counting accelerometer. This is an instrument that can count and record how many times aircraft accelerations exceed predetermined values; information which will be of great value in the field of aircraft structural fatigue research. There are many other developments going on, of course, which cannot be described at present; but from this short review some idea of the importance of operational research can be gained. Now the work is firmly established, and all technical and flying members of the Service should do what they can to help. For only by extension of this type of research will a proper compromise between the conflicting demands of aircraft structural safety and low structural weight—a matter vital to our operational efficiency—be reached.

A.R.B. NOTICES

The Council of the Air Registration Board announces the issue of the undermentioned.

British Civil Airworthiness Requirements:

Contents List, Issue 18, replacing Issue 17.

General Foreword, Issue 14, replacing Issue 13.

Section 'R', Issue 1, replacing subsections R3 to R12 (with Appendices) inclusive, under date June 29, 1951.

Critical Flow Through Convergent Nozzles

To the Editor

DEAR SIR,

In the June issue of AIRCRAFT ENGINEERING, Mr V. D. Naylor rightly asserts that, according to one-dimensional theory, the velocity at the throat of a Laval nozzle is the local sonic velocity, whether friction is present or not. However his proof rests on an expansion law pv^n=constant, when $n \neq \gamma$, and the throat velocity which he obtains differs according to the value of n. Both the assumption and the conclusion are false. The confusion which has existed on this point is, therefore, deepened.

In order that the problem should be settled once and for all I would like to establish the following propositions for a perfect gas:

(*a*) The velocity at the throat of a Laval nozzle is the local sonic velocity, with or without friction.

(*b*) The throat velocity depends only on the conditions at inlet to the nozzle and not on the friction characteristics.

(*c*) The expansion law in the neighbourhood of the throat is $pv\gamma$=const., with or without friction.

(*d*) On the enthalpy-entropy chart the expansion line is vertical at the point corresponding to the throat.

The equations governing adiabatic flow are:

Continuity $$\frac{d\rho}{\rho}+\frac{dv}{v}+\frac{dA}{A}=0 \;\ldots\ldots\ldots\ldots(1)$$

Momentum $$\frac{dp}{\rho}+v\,\frac{dv}{g}+c_f l\,\frac{v^2dx}{Ag}=0 \;\ldots\ldots(2)$$

Energy $$dI+v\,\frac{dv}{g}=0 \;\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Gas law $$\frac{dp}{\rho}-\frac{\gamma-l}{\gamma}\,dI-\frac{p}{\rho}\frac{d\rho}{\rho}=0 \;\ldots.(4)$$

Entropy $$Td\phi=dI-\frac{\gamma p}{\rho}\cdot\frac{d\rho}{\rho} \;\ldots\ldots\ldots\ldots(5)$$

The notation used is as follows:

ρ = density
v = velocity
A = area of cross-section
p = pressure
c_f = friction co-efficient
g = acceleration due to gravity
l = perimeter of nozzle.
I = enthalpy
γ = ratio of specific heats
T = absolute temperature
ϕ = entropy

From these equations we may derive two more, namely:

$$\frac{\left(\frac{\gamma p}{\rho}-\frac{v^2}{g}\right)}{\frac{v^2}{g}}\cdot dI=-\frac{c_f v^2}{Ag}\cdot dx+\frac{\gamma}{\rho}\cdot\frac{dA}{A} \;\ldots.(6)$$

and $$Td\phi=\frac{C_f l v^2}{Ag}\cdot dx \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

which may be put in the form

$$\frac{Td\phi}{dI}=\frac{\frac{\gamma p}{\rho}-\frac{v^2}{g}}{\frac{\gamma p}{\rho}\cdot\frac{l}{c_f l}\cdot\frac{dA}{dx}-\frac{\gamma v^2}{g}} \;\ldots\ldots\ldots\ldots(8)$$

and $$\frac{\left(\frac{\gamma p}{\rho}-\frac{v^2}{g}\right)}{\frac{v^2}{g}}=\frac{\gamma p}{\rho}\cdot\frac{1}{A}\frac{dA}{dI}-T\frac{d\phi}{dI} \;\ldots\ldots(9)$$

The condition for sonic velocity is $\frac{v^2}{g}=\frac{\gamma p}{\rho}$, as is well known.

Substituting this condition in equation (8) we find $\frac{d\phi}{dI}=0$, which proves proposition (*d*).

Substituting this result in (9), we find $\frac{dA}{dI}=0$. Since l decreases continuously as x increases it follows that $\frac{dA}{dx}=0$, which proves proposition (*a*).

Now in equation (6) we see that $\frac{dI}{dx}$ is infinite, showing that the region in which the 'isentropic' condition at the throat actually occurs is infinitely small.

Proposition (*b*) follows from integrating (3) and putting $I_1-I_{\text{throat}}=\frac{v^2}{g}=\gamma p/\rho$. Since $\gamma p/\rho$ depends only on temperature, there is only one heat drop from a given inlet enthalpy which gives rise to sonic velocity. As a result, the current definition of Mach No. is quite satisfactory in frictional flow.

Proposition (*c*) results from combining (4) and (5) and putting $\frac{d\phi}{dI}=0$. It implies that the small-stage efficiency is unity at the throat.

The fallacious proof that the sonic velocity is not attained in the throat was apparently first presented by Villey, and perpetuated by Kestin and Oppenheim. Essentially their proof runs as follows:

> 'In equation (6), the L.H.S.=0 when the velocity is sonic. Since $c_f \neq 0$ when friction is present, $dA \neq 0$. Therefore $\frac{dA}{dx}\neq 0$ when sonic velocity is attained.'

The fallacy is due to the careless use of infimitesimals .Although $\frac{\gamma p}{\rho}-\frac{v^2}{g}=0$ in (6), dI is infinite compared with dx and dA, so that the L.H.S. is actually indeterminate. It is only when the argument is presented in the manner above that an unequivocal solution is obtained.

Yours sincerely,
D. B. SPALDING

Engineering Laboratory
Trumpington Street
Cambridge
June 16, 1951

REFERENCES
Villey, J.: *Comptes Rendus Acad. Sci.* 201 (1935) 1478.
Kestin, J., Oppenheim, A. K.: I. *Mech. E. War Emergency Proe.* No. 43, p. 313.

The Author Replies

DEAR SIR,

The sole object of my paper was to show that a certain assumption would lead to certain conclusions. The question of whether the assumption was true or false or even if a sense existed in which it could be true or false was of no moment.

Mr Spalding says it is false.

As it happens, I believe it to be true—true in the sense Mr Spalding has in mind.

It is confirmed by experiment that for a particular nozzle the inlet and outlet conditions are governed by a constant value of n as if the pressure and volume were connected by a law of the form pv^n=constant. It is confirmed by experiment that the limiting velocity is less than the value given by $\sqrt{\frac{\gamma p}{\rho}}$ and further, that if this limiting velocity is equated to $\sqrt{\eta_\infty npv}$, it gives the same value of n referred to above.

I do not feel my paper leaves me under any obligation to comment on the rest of Mr Spalding's letter, but I would add that I do not share his belief that he has proved anything once and for all. His momentum equation contains a factor C_f which purports to express the mechanism by which mechanical energy is transformed into thermal energy through the agency of viscosity. It implies that the fluid is in intimate contact with the nozzle during the flow, which is far from being the case. Further, it takes no account of the shape of the inlet which is of decisive importance in deciding the actual flow within the nozzle.

Yours faithfully,
V. D. NAYLOR

A Further Comment

DEAR SIR,

The main point of Mr Naylor's article[1] has little need of experimental support, for it is well established in the theory of acoustics. So long ago as 1860 Helmholtz[2] calculated the velocity of sound in a gas confined in a pipe, and found it to be less than $\sqrt{(\gamma p/\rho)}$, the 'free space' value.

The effect of viscosity and thermal conductivity on the velocity of sound in a pipe can be treated by dimensional analysis. Write the sound wave equation (for one dimension) approximately as

$$\frac{\partial^2 u}{\partial t^2}=\eta\frac{\partial p}{\partial \rho}\cdot\frac{\partial^2 u}{\partial x^2}$$

where η is an 'efficiency' factor. The velocity of propagation of the wave is then $\sqrt{(\eta\partial p/\partial\rho)}$, so that η is identical with Mr Naylor's 'small stage efficiency'. $(1-\eta)$ is a function of the independent variables:

N, the frequency of the sound
d, the diameter of the pipe
h, the mean height of the roughness on the pipe walls.

And of the following properties of the gas:

v, the kinematic viscosity
k, the thermal conductivity
Cp, the specific heat, at constant pressure
γ, the ratio of the specific heats

These may be combined into the four dimensionless groups:

$v/Nd^2, \gamma, h/d$, and vCp/k.

The last is well known as the Prandtl Number, (Pr).

Helmholtz[2], considering the effect of viscosity alone, derived the relation (for a circular pipe):

$$(1-\eta)^2=2(v/Nd^2) \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\; (1)$$

In 1868, Kirchhoff[3] included the effect of thermal conductivity, and obtained

$$(1-\eta)=\left[1+\frac{\gamma-1}{\sqrt{(\gamma Pr)}}\right]\sqrt{\left(\frac{2v}{Nd^2}\right)} \;\ldots\ldots\; (2)$$

Equation (2) was verified by Kaye and Sherratt[4], who found that it gave values of $(1-\eta)$ which were about 10 per cent too high for smooth tubes (glass, copper), and 30 per cent too low for rough tubes (carbon). Thus an empirical correction could be obtained for the roughness parameter h/d.

I quote these results because they seem to be generally unknown to aerodynamicists. In particular most engineers assume that the velocity of sound in turbine nozzles and jet pipes is given by the free space value, and Mr Naylor has done well to draw attention to a serious error. It must be remembered that although sound waves are **adiabatic**, this only implies that the gas conductivity may be neglected, and is not synonymous with **isentropic**. A flow is isentropic only if the gas has no viscosity, and there are no shock waves present; and only in this case is the velocity of sound equal to $\sqrt{(\gamma p/\rho)}$. There are two occa-

(*Concluded on p. 245*)

Aircraft Engineering

English–French Vocabulary of Aeronautical Terms

Prepared by
M. Chalmette

Based upon British Standard 185: 1950 ***Glossary of Aeronautical Terms***

Alternative English terms are printed within brackets; subsidiary English terms are in *italics*; while American words, where they differ, are in normal type.

Les termes anglais équivalents sont imprimés entre parenthèses; les termes anglais subsidiaires sont en *italique*; les termes américains, lorsqu'ils existent, sont en caractères normaux.

(*Continued from p. 208*)

SECTION 7 (Continued)

Transverse frames	Cadres transversaux
Inner ridge girder	Elément de l'anneau intérieur d'un cadre principal
Intermediate base struts	Entretoises intermédiaires entre deux anneaux extérieurs d'un cadre principale —paralleles à la membrane longitudinale
Intermediate radial strut	Entretoise (f) intermédiaire reliant les anneaux intérieur et extérieur d'un cadre principal
Intermediate transverse frame	Cadre secondaire (m) Cadre intermédiare (m)
Main radial strut	Entretoise principale reliant les anneaux intérieur et extérieur d'un cadre principal
Outer ridge girder	Elément de l'anneau extérieur d'un cadre principal
Wiring	Haubanage (d'aménagement)
Bulkhead wiring	Haubanage (m) de cloisonnement à l'endroit d'un cadre principal formant séparation entre les ballonnets à gaz
Gas-bag wiring	Dispositif d'haubanage renfermant chacun des ballonnets à gaz dans un dirigeable rigide
Circumferential gas-bag wiring	Cables entourant les ballonnets à gaz pour supporter la pression
Mesh wiring	Filet empéchant les ballonnets à gaz de frotter contre les membrures longitudinales
Wiring, structural	Haubanage (de structure)
Axial wire	Hauban axial dans un dirigeable rigide reliant les ferrures centrales de chaque cadre haubané et fixé aux extrémités avant at arrière de la carène
Catenary wires	Chainettes pour la transmission des charges en deux points déterminés
Chord wiring	Haubanage transversal d'un cadre principal
Circumferential outer-cover wires	Cables reliant les membrures longitudinales soit à l'extérieur soit à l'intérieur et auxquels se fixe le revêtement
Lift wires	Haubans de sustentation
Radial wiring	Haubanage radial. Haubans réunissant les points d'assemblage d'un cadre à sa ferrure centrale
Shear wires	Haubans de cisaillement. Haubans croisés en diagonale entre les cadres
Valves	Soupapes
Automatic valve	Soupape automatique
Crabpot valve	Soupape en tissu d'une construction spéciale commandée manuellement par un cable
Gas bag alarm	Dispositif relié à un ballonnet à gaz indiquant que la pression voulue a été atteinte
Gas hood	Manche d'échappement (f) Ouverture protégée sur l'enveloppe extérieure d'un dirigeable rigide par laquelle le gaz peut s'échapper
Manoeuvring valve	Soupape commandée manuellement
Valve hood	Capotage protégeant la soupape montée sur l'enveloppe contre les intempéries
Valve line	Cable commandant une soupape

C. Mooring and Handling
Amarrage et Manutention

Bumping bag	Sac amortisseur Amortisseur d'atterrissage
Centre point mooring	Amarrage par la pointe de proue du dirigeable
Centre point pennant	Cable pour amener un ballon au sol par moyen mécanique
Centre point rigging	Agrès auxiliaires aboutissant à un étrier sur lequel vient se fixer le cable d'amarrage
Main mooring wire	Cable principal d'amarrage s'engageant dans le cône d'amarrage
Mooring cone	Cone d'amarrage (m)
Mooring point	Point d'amarrage (m)—point du dirigeable spécialement renforcé à partir du dirigeable spécialement renforcé à partir duquel sont lachés les cables d'amarrage
Mooring spindle	Elément supportant le cône d'amarrage
Tail guy mooring	Cable d'amarrage de queue (m)
Trail rope	Guide rope (m)
Yaw guy wires	Cables latéraux de proue

SECTION 8—POWER PLANT
GROUPE MOTOPROPULSEUR

A. Main Types of Power Plant
Principaux Types de Moteurs

Composite engine	Moteur compound (m)
Gas turbine engine	Moteur à turbine à gaz (m)
Intermittent jet	Pulso-réacteur (m)
Piston engine	Moteur à piston (m)
Ram-jet engine	Stato-réacteur (m)
Rocket	Moteur à fusée (m)

B. General Terms
Généralités

Accessory gear box	Boîte d'entraînement des accessoires
Aero-engine	Moteur d'avion (m)
Auxiliary power plant	Groupe moteur auxiliaire (m)
Consumption	Consommation (f)
Specific consumption	Consommation spécifique
Cowling	Capotage (m)
Non-pressure cowling [*Sealed cowling*]	Capotage étanche
Pressure cowling [*Unsealed cowling*]	Capotage dans lequel la pression d'air est augmentée par la pression dynamique ou un dispositif compresseur
Height power factor	Coefficient de variation de puissance en fonction de l'altitude
Paired engines	Moteurs contigus (m.pl.)
Power rating	Valeur de puissance
Brake horse-power (b.h.p.)	Puissance au frein (f)
Power unit	Unité motrice (f)
Coupled-engine power unit	Unité motrice constituée par deux moteurs couplés
Double-engine power unit	Unité motrice comportant deux moteurs entraînant deux hélices coaxiales
Right-hand or clockwise accessory	Accessoires tournant dans le sens des aiguilles d'une montre
Right-hand or clockwise drive	Entraînement dans le sens des aiguilles d'une montre
Torque dynamometer	Frein dynamométrique (m)
Torque meter	Couplemètre (m)

Weights	Poids (m)
Dry weight	Poids à sec
Weight per horse-power	Poids au cheval
Weight per pound thrust	Poids par livre de poussée
Lubrication system	Système de graissage
Oil control valve	Clapet automatique pour circuit d'huile
Oil coolers	Radiateurs d'huile
Air intake oil cooler	Radiateur d'huile incorporé dans une prise d'air
Ducted oil cooler	Radiateur d'huile disposé dans un conduit
Mixed-matrix oil cooler	Radiateur d'huile combiné
Multi-element oil cooler	Radiateur d'huile à éléments multiples
Series oil cooler	Radiateur d'huile monté en série
Surface oil cooler	Radiateur d'huile de surface
Tank oil cooler	Réservoir—radiateur d'huile
Oil dilution system	Système de dilution d'huile
Pipes	Canalisations
Feed pipes	Canalisations d'alimentation
Scavenge pipes	Canalisations de récupération
Tank vent pipe	Tuyauterie de mise à l'air libre
Pumps	Pompes
Pressure pump	Pompe de pression (f)
Scavenge pump	Pompe de récupération (f)
Fuel System	**Système de carburant**
Booster pump	Pompe d'amorçage (f)
Fuel-jettison gear	Vide-vite (m)
Tanks	Réservoirs (m)
Auxiliary tank	Réservoir auxiliaire (m)
Drop tank	Réservoir largable (m)
[*Slip tank*]	
Gravity tank	Réservoir en charge (m)
Air intakes and guards	Prises d'air et protections
Air intakes	Prise d'air (m)
Intake air heater	Réchauffeur de prise d'air
Non-ramming intake	Prise d'air non soumise à la pression dynamique
Ramming intake	Prise d'air soumise à la pression dynamique
Plenum chamber	Chambre de tranquillisation (f)
Air filter	Filtre à air (m)
[*Air cleaner*]	
Filter element	Elément filtrant (m)
Dry-type filter element	Elément filtrant sec
Wet-type filter element	Elément filtrant humide
Momentum separation	Séparation par inertie
Ice guard	Grillage anti-givre pour protection de prise d'air
Gapless-type ice guard	Dispositif anti-givre monté à l'intérieur de la prise d'admission d'air et utilisé conjointement avec une prise d'air secondaire
Gapped-type ice guard	Dispositif anti-givre monté en avant de la prise d'admission d'air, formant ainsi une fente qui ne givre pas
Stone guard	Grille de protection contre la projection des corps solides
Starting Systems	**Dispositifs de démarrage**
Combustion starter	Démarreur à cartouche (m)
[Cartridge starter]	
Compressed-air starter	Démarreur à air comprimé (m)
Electric starter	Démarreur électrique (m)
Ground starter	Démarreur d'aérodrome
Hand starter	Démarreur à main
Inertia starter	Démarreur à inertie
Internal combustion starter	Démarreur à combustion interne
Turbine starter	Démarreur à turbine

Numbering of engines: Engines are numbered consecutively from port to starboard, irrespective of their arrangement in power units; the outer engine being No. 1. Where they are mounted in tandem, the forward engine in that particular set is given the lower number. Where engines are superimposed, the lower engine in that particular set is given the lower number.

Numérotage des moteurs: Les moteurs sont numérotés de babord à tribord, le moteur extérieur étant le numéro 1. Dans le cas des moteurs en tandem, le moteur avant est considéré comme le premier. Lorsque les moteurs sont superposés, le numérotage commence par le moteur inférieur.

C. Piston Engines
Moteurs à Pistons

Critical height	Altitude de rétablissement
Fuel grade	Indice d'octane (m)
Rich-mixture knock rating	Indice d'octane en mélange 'riche'
Weak-mixture knock rating	Indice d'octane en mélange 'pauvre'
Left-handed engine	Moteur à sens de rotation positif (sens inverse des aiguilles d'une montre, vu de la place du pilote)
Manifold pressure	Pression d'admission
Manifold pressure gauge	Indicateur de pression d'admission
Right-handed engine	Moteur à sens de rotation négatif
Types of engine	Types de moteurs
Arrow engine	Moteur de W
Axial engine	Moteur en barillet (m)
Compression-ignition engine	Moteur à allumage par compression
H-engine	Moteur en H (m)
In-line engine	Moteur en ligne (m)
Inverted engine	Moteur inversé (m)
Opposed-cylinder engine	Moteur à cylindres opposés
Opposed-piston engine	Moteur à pistons opposés
Radial engine	Moteur en étoile (m)
Multi-row radial engine	Moteur à plusieurs étoiles
Rotary engine	Moteur rotatif
Supercharged engine	Moteur suralimenté (m)
Supercompression engine	Moteur à taux de compression élevé
V-engine	Moteur en V (m)
Vertical engine	Moteur vertical (m)
X-engine	Moteur en X (m)
Engine Components	**Eléments constituant le moteur**
Location of Parts	Positionnement des pièces
The following are the standard adjectives for the location of parts, the engine being assumed in normal running position with the observer looking along it toward the propeller end: **Left Centre Right** **Front Middle Rear** **Top Centre Bottom** **On in-line engines the cylinders are numbered from the propeller end**	Les mots suivants sont utilisés comme adjectifs standard pour situer les pièces ou les accessoires moteur, celui-ci étant monté sur l'avion et l'observateur placé à la place du pilote, en regardant vers l'hélice: Gauche Centre Droite Avant Milieu Arrière Haut Centre Bas (côté supérieur) (côté inférieur) Dans les moteurs en ligne, les cylindres sont numérotés à partir du côté hélice
Connecting rod assembly	Embiellage (m)
Forked assembly	Embiellage à fourche (m)
Master and articulated assembly	Embiellage à bielle maitresse et bielles secondaires articulées
Side-by-side assembly	Embiellage côte-à-côte (m)
Slipper-type assembly	Embiellage du type à glissière
Big end	Tête de bielle (f)
Small end	Pied de bielle (m)
Wrist pin end	Téte de bielle secondaire (f)
Gudgeon pin	Axe de piston (m)
[Piston pin]	
Floating gudgeon pin	Axe de piston flottant
Wrist pin	Axe de tête de bielle secondaire
[*Knuckle pin*]	
Crankcase sump	Puisard (m)
Flame trap	Dispositif anti-retour de flamme
[Induction flame damper]	
Junk ring	Segment de fourreau (m), moteurs à fourreaux
Maneton	Maneton (m), démontable dans un moteur rotatif ou en étoile
Piston rings	Segments de piston
Gas ring	Segment de feu (m)
Obturator ring	Segment d'étanchéité (m)
Scraper ring	Segment racleur (m)
[*Oil ring*]	
Fuel Supply	**Admission d'essence**
Accelerator pump	Pompe de reprise (f)
Boost control	Régulateur de pression d'admission
Variable-datum boost control	Régulateur de pression d'admission fonctionnant conjointement avec la manette des gaz
Boost control over-ride	Dispositif de commande indépendant permettant d'obtenir une pression d'admission plus élevée que celle normalement assurée par le régulateur de pression—pression utilisée pour obtenir une surpuissance du moteur
[Boost control cut-out]	
Boost gauge	Manomètre de pression d'admission
Boost pressure	Pression d'admission (f)
Bulk-injection carburettor	Carburateur soufflé (m)
Bulk-injection pump	Pompe à injection de combustible remplissant les mêmes fonctions qu'un carburateur soufflé
Direct-injection pump	Pompe à injection directe (f)
Float-type carburettor	Carburateur à flotteur (m)
Induction manifold	Canal d'admission (m)
Intercooler	Refroidisseur d'air après le compresseur
[Aftercooler]	
Mixture control	Réglage de richesse
Automatic mixture control	Réglage automatique de richesse
Primer	Injection au départ

(To be continued)

Research Reports and Memoranda

Under this heading are published regularly abstracts of all Reports and Memoranda of the Aeronautical Research Council, Reports and Technical Memoranda of the United States National Advisory Committee for Aeronautics and publications of other similar Research Bodies as issued.

CANADA

NATIONAL RESEARCH LABORATORIES

Ottawa

DIVISION OF MECHANICAL ENGINEERING

AERODYNAMICS LABORATORY

MA-232. August 9, 1950. Ejector Theory and Its Application to Induction Type Wind Tunnels. By W. R. Laidlaw.

The possibilities of the induction type wind tunnel for producing high speed flows are unlimited. This report presents a general ejector theory which may be applied to all types of induction tunnels, with special emphasis being given to the design and analysis of the gas turbine type tunnel. The results of experiments on a typical ejector tunnel configuration are presented with the purpose of establishing this theory as a practical basis for future design and analysis of all types of high speed induction wind tunnels.

ENGINE LABORATORY

ME-186. August 28, 1950. Spray Nozzles for the Simulation of Cloud Conditions in Icing Tests of Jet Engines. By N. Golitzine, C. R. Sharp and L. G. Badham.

The report describes tests on pneumatic and swirl type spray nozzles, for simulating natural cloud conditions in icing tests of jet engines. Figures are given for the water droplet sizes obtainable in sprays from nozzles of different sizes, at various conditions.

In the swirl type nozzles tested, there was imparted to the water jet, issuing under pressure, a swirling motion, which caused atomization. It was found that, at a given pressure, atomization was finer, the smaller the nozzle, and with a given nozzle atomization became finer with increase in pressure up to about 1,000 lb./in.^{2}, after which pressure had no appreciable effect. The finest spray obtainable with the smallest nozzle, which it was feasible to make in the laboratories, did not give droplets small enough to cover fully natural cloud conditions.

The pneumatic type nozzles tested were of simple construction: compressed air expanded through an orifice; water was fed through a tube to the centre of the orifice, and was there atomized by the expanding air. There were no fine passages either in the air or water outlets, hence there was little possibility of obstruction. It was found that, with air pressures above the critical (about 13 lb./in.^{2} gauge), when the air reached some velocity, droplet size in any one of the pneumatic nozzles tested was primarily dependent on the water to air mass flow ratio. Hence, in a given nozzle, it was possible to obtain any desired droplet size, by varying the air pressure, or the rate of water flow, or both. The range of droplet sizes covered in the tests was equivalent to that found in natural clouds.

FUELS AND LUBRICANTS LABORATORY

MF-2905. December 5, 1950. The Viscosity-Surface Tension Relation for Petroleum Fuels. By W. Sacks.

Measurements have been made of the viscosity and surface tension at 25 C. of a series of fuels covering the viscosity range from gasolines to heavy fuel oils. The relation between log γ and log ν is linear and an equation is given which provides a good correlation of the data for fuels with viscosities greater than one centistoke.

MF-2891. July 25, 1950. Literature Review on the Prevention of Ice Crystal Formation in Fuels. By J. M. Lloy.

The object of this inquiry was to review and summarize available information on the formation of ice-crystals in fuel, in preparation for a study of chemical methods for preventing filter plugging by ice-crystals. A bibliography of published literature, with summaries, is appended.

It was found that work has been done on the prevention, commercially, of the separation of alcohol-gasoline motor fuels into two layers in the presence of water. The problem of filter plugging by ice-crystals, either from suspended or entrained water, has received scant attention. Several materials and methods appear to be of interest.

STRUCTURES SECTION

MM-222. May 4, 1950. Report on Observations of the Behaviour of a Family of Plastic Wing Models Under Dead Weight and Aerodynamic Loads. By A. H. Hall.

A study was made to assess the suitability of cellulose acetate for structural wing models and at the same time to examine, experimentally, the effect of wing taper on torsional divergence.

It was concluded that the material is not suited to accurate and repeatable measurements when the forces vary in duration.

Wind-tunnel data required adjustment for movement of shear centre with shear load and for variation of torsional stiffness with shear load and temperature. The wings of low taper gave divergence coefficients in conformity with theory, but for high taper, values much lower than theoretical were obtained. The nature and magnitude of the adjustments, and in the case of high taper, excessive extrapolation, minimize the value of these results.

ENGINEERING SECTION

MM-225. August 15, 1950. Aircraft Ski Research in Canada. By G. J. Klein.

This paper discusses the comprehensive research programme aimed at the development of improved skis for aircraft which has been carried out in Canada during the past twenty years. The investigations of (a) the sliding resistance and adhesion of skis on snow; (b) the aerodynamics of skis with particular reference to their instability in pitch, and (c) the dynamic loads on skis while landing are described. The hitherto unpublished results of recent trials of skis on deep, soft snow throw new light on the problem and stress the importance of designing aircraft skis to suit the conditions of the snow on which they are intended to operate. General information on the relevant features of snow is also included. By bringing the various researches together in a paper of this kind, it has been possible to draw general conclusions which differ in a number of respects from those previously published.

SUPERSONICS AND GAS DYNAMICS SECTION

MT-10. January 18, 1950. Shock Tube Theory and Applications. By J. Lukasiewicz.

The theory of shock tube flow is presented in a form convenient for the aerodynamic design of shock tubes. Tables and graphs of the required functions, covering the whole range of values of the specific heat ratio, are included.

Application of shock tubes to investigation of compressible flow is examined. In particular, the use of shock tubes as sub- and supersonic tunnels, as aeroballistic ranges (including hypersonic speeds) and for investigation of propagation of continuous waves, shocks (including variable specific heat and relaxation time effects) and interactions is considered.

MT-11. January 18, 1950. Flow in a Shock Tube of Non-Uniform Cross-Section. By J. Lukasiewicz.

Flow in a shock tube which consists of two sections of different cross-sectional area, the section initially under higher pressure being the larger one, is considered on the assumptions of one-dimensional motion. It is shown that quasi-steady flows and shocks of a given Mach Number are produced with an initial pressure ration about one-third smaller than that required in a uniform cross-section shock tube. The length of the higher pressure tube section for a given duration of quasi-steady flow behind the contact surface is about 8 per cent smaller.

NETHERLANDS

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Report F.76. A Generalization of Prandtl's Equation. By A. van Heemert.

In this report generalizations of Prandtl's equation are derived applying to:

(i) straight wings of large aspect ratio under yaw; the final result is equation (3·19),

(ii) symmetrical swept-back wings with a symmetrical distribution of vorticity, the wing consisting of two straight parts, each having large 'aspect ratio' when considered apart and joining of course, in the plane of symmetry; the final result is, in this case, given by (4·6) and (4·25).

In both cases the result is a genuine generalization of Prandtl's equation, as it expresses the downwash at the surface of the wing in the vorticity distribution associated with it and, further, as it contains only line integrals to be extended, e.g., over the 1/4-chord line.

The resulting equations, mentioned above, express the downwash at the surface after assuming a suitable expansion for the spanwise components of the vorticity distribution viz. that given by (3·1). Special care has been taken (compare Appendix 3) to ensure the continuity of the vorticity distribution along the root-chord in the case of a swept-back wing.

Applications, made thus far only of (3·19), indicate the adequacy of the obtained results (compare [3] and [4]).

It is remarked that throughout the present report the chord-wise vorticity distribution is taken into account. This is in contrast with the well-known Weissinger lifting-line method ('Traglinienverfahren') compare [9]) which constitutes the main method used, up till now, to calculate the distribution of the circulation for swept wings.

GREAT BRITAIN

AERONAUTICAL RESEARCH COUNCIL

H.M. Stationery Office, London

R. & M. No. 2433. The Use of Rubber Models in Stress Investigations. August 1942. (4*s*.)

Part I. Description of a Proposed Method and Discussion of the Theoretical Considerations Involved. By D. Williams.

Part II. Use of Method to Explore Stresses Around Holes in Flat Sheet under Tension. By R. D. Starkey and F. Grinsted.

Part III. Use of Method for Stress Investigations of Two New Types of Problem. By D. M. A. Leggett and R. P. N. Jones.

In Part I the possibility of using rubber sheet subjected to large strains (of the order of 10 to 30 per cent) for the purpose of stress investigations is examined, and reasons are given for expecting useful results from the application of the idea to aeronautical structural problems.

In Part II the method is used to explore the stresses around holes of various shapes, and variously reinforced, in flat sheets in tension.

In Part III the method is applied, first to obtain the stresses around a semi-circular notch cut in the side of a sheet strip under tension; and second to obtain the stress distribution in a sheet strip lightened by a series of circular holes when the strip is subjected to shear forces.

R. & M. No. 2455. Further Wind-tunnel Tests on the Supermarine S.12 40, a Monoplane Amphibian with a Variable Incidence Wing. By H. V. Becker, R. Hills and H. Hogg. May 1944. (3*s*.)

Further wind-tunnel tests have been made on the Supermarine S.12/40 to cover tests with a conventional tail layout, and to complete the data on the 35 deg. and 40 deg. dihedral tails.

A comparison of the efficiences of the dihedral tails is included, and the results of some preliminary tests with a 20 deg. dihedral tailplane with twin and fins are given in an Appendix.

Directional and longitudinal stability in take-off and landing conditions, and elevator and rudder power in cruise condition were measured.

The conventional tail is unsatisfactory laterally due to low efficiency caused by strut wake, and tail buffeting is likely. Longitudinal stability is similar to the 40 deg. tail.

For a tailplane with a dihedral angle y the values of the lift slopes are proportional to $\cos^2 y$, and the side force constants are similarly proportional to $\sin^2 y$.

A 20 deg. dihedral tailplane with end fins gives satisfactory directional stability and rudder power. Further tests on a modified form of this tail are to be made.

R. & M. No. 2456. Wind-tunnel Tests on the Folland E.28/40. High-Wing Monoplane with a Variable-Incidence Wing. By R. Hills, R. H. Whiteley and F. N. Kirk. January 1944. (11*s*.)

Part I.

Wind-tunnel tests have been made on a 1/15th scale model of the Folland E.28/40, an experimental aircraft designed as a torpedo bomber and for reconnaissance duties with the Fleet Air Arm. To satisfy landing and take-off requirements the aircraft is fitted with a variable-incidence wing, a full-span 40 per cent. chord Fowler flap and a 25 per cent. chord leading-edge slat.

The main purposes of the tests were to investigate:
(1) The maximum lift which could be obtained.
(2) Changes in longitudinal trim and stability with slipstream, including the effect of changing the vertical position of the tail.
(3) Change of trim on lowering flaps and changing wing setting.
(4) Ground effect on trim during landing and take-off.

Conclusions.—(1) Without slipstream a maximum lift coefficient of 4·05 (3·90) trimmed was obtained. The increments ($\Delta C_{L\,\max}$) due to flaps and slats were (*a*) due to flaps, 1·95 (*b*) due to slats, 0·90.

(2) Due to the high position of the thrust-line-relative to the C.G., slipstream has in general a stabilizing effect. Longitudinal stability should be adequate with the conventional tail position, and no advantage is to be gained by raising the tail to the top of the fin.

(3) During the operation of lowering the flaps and changing the wing setting before landing, large changes of elevator angle can be avoided by lowering the flaps first and then opening the leading-edge slats and using the change of wing setting to retrim the aircraft to a lower speed.

(4) When the wing is set at a large angle to the fuselage, there is a danger of the tail stalling, when the engine is switched on owing to the large increase in downwash angle, and it will be necessary to fit a leading-edge slat to the under surface of the tail to prevent this stall.

(5) Elevator power is sufficient for take-off and landing with the design C.G. forward limit ($h = 0\cdot30c$).

(6) Small elliptical endplates give a slight increase in maximum lift (3 per cent.) and a decrease of 12 per cent. on induced drag.

(7) Rolling moments due to a 40 per cent. chord aileron of 25 per cent. semi-span are adequate for lateral control ($C_i \simeq$ p·05) but the maximum lift coefficient is reduced by 0·3 by decreasing the overall flap span to 75 per cent.

Part II. Further Wind-Tunnel Tests on the Folland E.28/40—Without Ground. By E. Priestley, H. V. Becker and E. C. Brown.

The present wind-tunnel tests were made on a 1/8th scale model of the Folland E.28/40, an experimental aircraft designed for torpedo-bombing and reconnaissance work with the Fleet Air Arm. The aircraft has a variable-incidence wing, 75 per cent. span Fowler flaps, and wing and tail slats.

Previous tests have been made on a 1/15th scale model with full-span Fowler flaps and wing slats; some results were also obtained with 75 per cent. flaps.

Range of Investigation.

(1) Maximum Lift.

(2) Longitudinal stability and trim for take-off, landing and baulked landing conditions under the appropiate throttle conditions.

(3) Effect of tail slats on tail stalling and on longitudinal trim and stability.

(4) Lateral stability (n_v and l_v) and rudder power without slipstream.

(5) Pressure distribution over the bomb-aimer's panel at high speed.

Conclusions

(1) Maximum lift, the results of these and the previous tests may be summarized as follows for the no-slipstream case:

Trimmed $C_{L.\mathrm{Max}}$	Present model (75 per cent. span flaps)	1/15th scale mdel
Due to flaps	Not measured separately	1.90 Full-span flaps
Due to slats		0.90
Due to flaps and slats ..	2.4	2.65
Total ..	3.55	3.90 (3.50, 75 per cent. span flaps).

A trimmed C_L of 4·6 was obtained with slipstream and wing setting $i_w = 14$ deg. relative to thrust line.

(2) With flaps and slats retracted, $i_w = 4$ deg. (cruising and high-speed flight), there is a considerable longitudinal stability margin with aft C.G. With flaps and slats open the aircraft is stable in the glide except at high speeds with full load (aft C.G.). Slipstream, however, reduces the stability so that even with forward C.G. the stability is only about neutral in the baulked landing condition and negative in take-off and climb.

The changes in elevator angle to trim due to slipstream without ground are in general small, the largest being +7 deg., due to opening the throttle just before landing at a C_L of 3·3 (just above the stalling speed); at lower lift coefficients the change is considerably reduced.

The elevator angle to trim at high speed (350 m.p.h., C.A.S.) is 9-10 deg., again with tail setting −1·7 deg.

(3) The tail slats are effective in preventing tail stalling over a range of lift extending from negative values right to the wing stall. Opening the slats improves the longitudinal stability.

(4) Values of n_v and l_v are 0·082, −0·052 for the landing condition (no slipstream); 0·032, −0·057 with flaps and slats retracted, wing setting $i_w = 4$ deg.

(5) The air forces on the bomb-aimer's panel are small, varying from a pressure of $0.18 \times \frac{1}{2}pV^2$ at the rear to a suction of $0\cdot09 \times \frac{1}{2}pV^2$ over the forward part.

R. & M. No. 2468. Pitot-tube Readings near Shock Waves in the N.P.L. and R.A.E. High Speed Tunnels. By R. G. Fowler. February 2, 1945. (3*s*.)

It is shown that in recent tests in the Royal Aircraft Establishment High Speed Tunnel pitot readings near shock waves agree with theory as well as would be expected. Comparative readings in the National Physical Laboratory 20 × 18 in. tunnel confirmed that the condensation of atmospheric humidity has a large but unpredictable effect on pitot pressures in this tunnel and in all tunnels of this type.

R. & M. No. 2478. Distortion of Control Surface Panels. By D. M. A. Leggett and R. G. Chapman. November 1944. (5*s*. 6*d*.)

This report provides data for the design of control surface panels of any required rigidity, flight experience having shown that distortion of control surface panels, due to airloads, often has a serious effect on the pilot's operating force in the case of large or high-speed aircraft.

The report falls naturally into two parts. Part I is purely theoretical and contains estimates of the distortion that is likely to occur with different types of construction and for various aerodynamic loading. Part II is primarily experimental and consists of a detailed account of tests made on various types of control surface.

The experimental results described in Part II show that the theoretical estimates given in part I for the distortion of fabric panels under uniform pressure lie between 100 per cent. and 125 per cent. of the practical values. For metal panels the same accuracy can be obtained for pressure above 2 lb./in.², but below this pressure, the simple theory developed in Part I is inadequate owing to the presence of intercostal or spanwise stringers and to lack of rigidity of the edge members.

Theory and experiment indicate that for panels under a triangular chordwise pressure distribution, the deflexion at a point where the linearly varying pressure is p, is almost the same as the deflexion of the same point when the pressure p is uniform. Theoretical estimates of the deflexion of such points are, therefore, of the same order of accuracy as those relating to panels under uniform pressure.

On the basis that panel distortion due to given aerodynamic loading is not to exceed some specified amount, the results given in this report suggest that of available cover materials, fabric provides the lightest structure. The results also suggest that closely spaced ribs, or ribs and intermediate chordwise stringers, constitute a more efficient method of reinforcing the cover than ribs and stringers.

At the end of the report a comparison is made between the theoretical estimates of Part I and the experimental results of Part II.

R. & M. No. 2507. Aileron Tests on a Spitfire. By D. E. Morris and M. B. Morgan. With an Appendix by F. Grinsted. April 1941. (2*s*. 6*d*.)

Comprehensive aileron tests were made on a Spitfire to investigate poor rolling characteristics at high speeds. Simultaneous records were taken of the aileron angle and the angle of bank of the aircraft at various speeds. Stick forces for known aileron angles were measured and also the amount of wing twist due to ailerons. The aileron reversal speed was shown to be about 480 m.p.h. V_i, which is lower than the estimated value using conventional theory, but agrees well with the estimate based on the value of a_2/a_1 deduced from flight measurements. At 400 m.p.h. the ailerons lose 65 per cent of their effectiveness due to wing twist; at this speed Kb_2 for the ailerons is −0·18, which means that a stick force of 54 lb. will give a mean aileron angle of 3 deg.

R. & M. No. 2510. Experiments on the Balancing of Ailerons by Geared Tabs and Trailing-edge Strips. By L. W. Bryant, C. H. Burge, N. E. Sweeting and J. R. Greening. April 1941. (5*s*. 6*d*.)

It was known from experiments on a parallel aerofoil that a combination of geared tabs and trailing-edge strips provided a means of adjusting $-b_2$ to a reasonably small value, whilst increasing $-b_1$ so that the ratio b_1/b_2 should be large enough to ensure a favourable value of the response factor $(1 - nb_1/b_2)$ for a control. In order to test the suitability of this method of lightening controls for application to ailerons, experiments were carried out on a model Spitfire wing. It was confirmed that b_2 is little affected by adding a tab at constant deflexion; and that trailing-edge strips increase both $-b_2$ and $-b_1$, particularly $-b_1$. Four different tab sizes were tested, and it should be possible to interpolate the results to deduce the hinge moments for a wide range of tabs with and without strips. Loss of rolling moment due to geared tabs of about 1 : 1 ratio was also measured; this loss is not serious.

As a method of increasing b_1/b_2 the combination of geared tabs and trailing-edge strips suffers from the drawback that b_1/b_2 has its maximum value at 4 deg. incidence corresponding to a low speed of flight. This is presumably due to the fact that the wing section is not symmetrical.

THE COLLEGE OF AERONAUTICS

Cranfield, Bletchley, Bucks

Report No. 45. Tests on the General Instability of a Stiffened Metal Cylinder under Axial Compression. By W. R. Heald. April 1951. (5*s*.)

A thin stiffened metal cylinder liable to general instability was tested under axial compression and an investigation was made into possible methods of predicting the critical load from non-destructive tests. Particular attention was paid to the perturbation loading technique. The cylinder was finally tested to destruction and the actual failing load compared with the values given by various theories and empirical relationships.

It was not possible to predict the critical load from measurements of the normal restraint coefficient (or radial stiffness); the stiffness did not vary with end load according to any simple law, being sensitive to the amount of skin buckling and falling off very rapidly over the last small fraction of the load.

The possibility was indicated of finding the buckled wave form at failure from measurements of the cylinder distortion during comparatively light compression load tests and/or radial perturbation loads.

Very good agreement was obtained between the failing load on test and the values predicted from Hoff's semi-empirical law and van der Neut's theoretical relationship, though in both cases the solution depended on some test information.

Report No. 46. The Use of a Potential Flow Tank for Testing Axi-Symmetric Contraction Shapes suitable for Wind Tunnels. By A. W. Babister, W. S. D. Marshall, G. M. Lilley, E. C. Sills and S. R. Deards. April 1951. (5*s*.)

The report gives details of tests in the potential flow tank on a series of axi-symmatric contraction shapes. The tests were in connexion with the design of the 8 ft. × 6 ft. wind tunnel and a water tunnel. The potential flow tank provides a simple method of modifying an axi-symmetric contraction shape to meet given requirements. The report shows that small modifications to a theoretical contraction shape for the 8 ft × 6 ft. wind tunnel give a great reduction in total length with only a small adverse velocity gradient at the high speed end of the contraction. The tests were concerned with contraction ratios of the order of 7:1, which is considerably larger than the contraction ratio of 4:1 tested by Cheers[2]; thus the electrolyte at the high speed end of the contraction was comparatively shallow, and special care was needed in manufacturing the model and in designing the electronic equipment. Details are given of the precautions taken in consequence. The overall error of the apparatus is ±2 per cent. and suggestions are given for increasing this accuracy.

Report No. 47. Vibrations of a Swept Box. By J. R. M. Radok*. April 1951. (5*s*.)

The equations of motion of a uniform swept box with stringers and ribs are deduced. For the case of vibrations of a cantilver they are transformed into integral equations, an approximate method of solution of which is indicated.

***Mr Radok is a member of staff of the Structures Section of the Aeronautical Research Laboratories, Department of Supply, Australia, and is at present studying at the College. Acknowledgment is paid to A.R.L. for their agreement to the publication of this as a College report.**

Important Developments in Aeronautical Research in Canada

An Official Announcement Regarding the Formation of the National Aeronautical Research Committee and the New National Aeronautical Research Establishment at Uplands

IN January of this year a brief news item in the Canadian Press announced that the Government had approved the formation of a National Aeronautical Research Committee and the creation of a National Aeronautical Establishment. This statement indicated that a change had been made in the organization of the Government's aeronautical research activities. Because of the importance of this reorganization, and the favourable results which are expected therefrom, it is desirable that all who are interested in aviation in Canada should be fully acquainted with the changed organization and the reasons which prompted it.

During the Second World War considerable expansion took place in the aircraft industry in Canada, with the effort devoted almost exclusively to the construction of military aircraft which had been designed and developed initally either in the United Kingdom or in the United States of America. Since the end of the war, however, a profound change has taken place within the industry, due predominantly to military considerations. This change stemmed from the Government's policy of actively fostering the development of military aircraft and engines in Canada. The great importance of aircraft in warfare, coupled with the fact that the growth of bomber performance rendered Canada liable to direct air attacks in any future hostilities, meant that grave risks would be inherent in any policy that left Canada fully dependent on the U.K. or the U.S.A. for her defensive aircraft. In order to encourage the fullest development of the industry and to obtain the broadest possible benefits to the people of Canada, the policy of the Government was extended to include support for the design and development in Canada of modern transport aircraft. Considerable effort has therefore been expended during the last few years in building up in Canada an aircraft industry of high calibre. In time of war the high quality of the aircraft produced by such an industry would contribute materially to the efficiency of the R.C.A.F. as a fighting service.

The aircraft industry has always leaned heavily on its own and Government research facilities. The extremely rapid development of military aircraft and the science of aeronautics in the last five to ten years has placed military aviation on the threshold of a new era of unbounded possibilities. At the same time, the problems facing the aircraft designer have grown in magnitude and in many cases he is working in hitherto unknown territory. If the industry is to progress, the designer must be more than ever dependent on the results of aeronautical research. On the other hand, if they are to serve the needs of industry, the research facilities must be of the highest order of excellence. They must be of suitable scope to tackle the new problems created by the needs of military aviation and they must be staffed by people with the best training, experience and ability. The importance of research to aeronautical development was emphasized by Dr Hugh Dryden, Director of the National Advisory Committee for Aeronautics in the U.S.A. in his Wilbur Wright lecture before the British Royal Aeronautical Society in April 1949—'The aeronautical research scene is part of a larger territory which covers all of the diversified activities connected with the development, production and use of aircraft. Progress is made by continually building on an increasing body of knowledge. Research is the key vitamin in promoting this growth. If it were absent, growth would cease as soon as the accumulated supply of knowledge was fully exploited by practical application.'

The impressive post-war growth of the aviation industry to its present high level of activity and the present world situation have produced an urgent need for increased effort in aeronautical research for defence purposes. In view, however, of the mutual dependence of military and civil aeronautical development and the importance which civil aviation now enjoys in its own right in Canada, it is necessary to provide continuing research and development support for the problems posed by civil aviation. There has been therefore an awareness of the need for a co-ordinated plan for the improvement of aeronautical research facilities in order that the maximum benefit may be derived for both military and civil aviation. The Aeronautical Laboratories of the National Research Council came into being in 1929 but, mainly because of the depression in the 1930's, they remained undeveloped until the Second World War necessitated their growth and expansion. These laboratories are still modest in both equipment and staff in relation to the overall importance and magnitude of aviation. It has been difficult, particularly in recent years, for equipment to keep pace with the developments and requirements of the industry and in serving a field which is changing so rapidly considerable ingenuity must be exercised if equipment for research and development is not to become obsolescent.

With the object of achieving an orderly development of the facilities and a closer integration of the requirements for military and civil aeronautical research and development, the National Research Council and the Defence Research Board have for some time been exploring the possibilities of creating a National Aeronautical Establishment which could be administered as a joint military and civil establishment under appropriate arrangements. It was finally decided that the National Research Council will operate the Establishment as a separate agency along lines somewhat similar to those on which it operates the Atomic Project at Chalk River. Detailed administration will be the direct responsibility of the National Research Council with policy determined by the National Aeronautical Research Committee. This method of organization was approved by the Government and the National Aeronautical Research Committee was made responsible to a Sub-committee of the Privy Council Committee on Scientific and Industrial Research, consisting of the Chairman of the Privy Council Committee and the Ministers of National Defence and Transport. On defence matters, however, it has been decided that the National Aeronautical Research Committee will report directly to the Cabinet Defence Committee. By organizing theNational Aeronautical Establishment in this manner, the need for new legislation has been avoided and funds for the operation of the Establishment will be included in the estimates of both the National Research Council and the Defence Research Board.

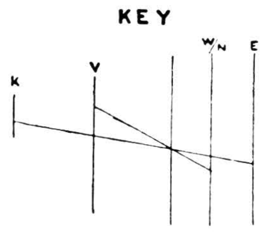
In the United Kingdom, the United States and in some other countries, notably Germany, aeronautical laboratories of major importance have always been established at sites where flight research facilities can be developed. The well-known Royal Aircraft Establishment at Farnborough and the National Advisory Committee for Aeronautics Laboratories at Langley Field are typical examples. There are obvious unquestioned advantages in such an arrangement. When the Laboratories of the Division of Mechanical Engineering, National Research Council, were established on the Montreal Road, it was hoped that proximity to the R.C.A.F. Station at Rockcliffe would be beneficial. However, when the Flight Research Section was established in 1946, operational difficulties rendered it undesirable to locate these at Rockcliffe and the unit was eventually established at Arnprior, Ontario, which offered the best available among the possible sites not too distant from the parent laboratory. The physical limitations of the Arnprior aerodrome have now become a serious handicap to the work of this unit, which is at times engaged with projects involving aircraft the performance of which does not permit them to be operated from the aerodrome. It became essential therefore to consider enlarging the Arnprior aerodrome, or moving the unit to some other aerodrome of suitable size or to some site at which a new aerodrome could be constructed. The growing importance in Canada of flight testing and research and the requirement for a larger aerodrome on which to conduct these activities are an integral part of the broader problem of achieving an orderly expansion of our aeronautical research facilities. It was appreciated that an opportunity was presenting itself for laying the foundations of an aeronautical research establishment which would be immediately adjacent to an aerodrome of sufficient size to handle all present flight test and research requirements and capable of expansion to deal with the reasonable needs of the distant future. It was important that a site should be chosen as close as possible to the present Aeronautical Laboratories on the Montreal Road and, since a requirement existed for improved aerodrome facilities to meet the needs of both the R.C.A.F. and civil aviation in the Ottawa area, it was agreed that a common site to meet all these requirements was practicable. After some study it was decided that the Ottawa aerodrome at Uplands should be developed for these purposes. The existing Aeronautical Laboratories of the Division of Mechanical Engineering, together with new flight research facilities to be provided at Uplands by the Defence Research Board, will form the nucleus of the National Aeronautical Establishment which will be operated by the National Research Council on behalf of the National Aeronautical Research Committee. Mr J. H. Parkin, C.B.E., the present Director of the Division of Mechanical Engineering, National Research Council, was appointed Director of the new establishment.

The National Aeronautical Research Committee, which provides the direction on broad policy matters for the National Aeronautical Establishment, is a four-man Committee consisting of the President of the National Research Council, the Chairman of the Defence Research Board, the Chief of the Air Staff, R.C.A.F., and the Chairman of the Air Trans-

(*Concluded on p. 245*)

Brake Energy Monogram

KEY



$$E = \frac{1}{30} \times \frac{KWV^2}{N} \text{ V in m.p.h.}$$

$$= \frac{1}{22.7} \times \frac{KWV^2}{N} \text{ V in knots.}$$

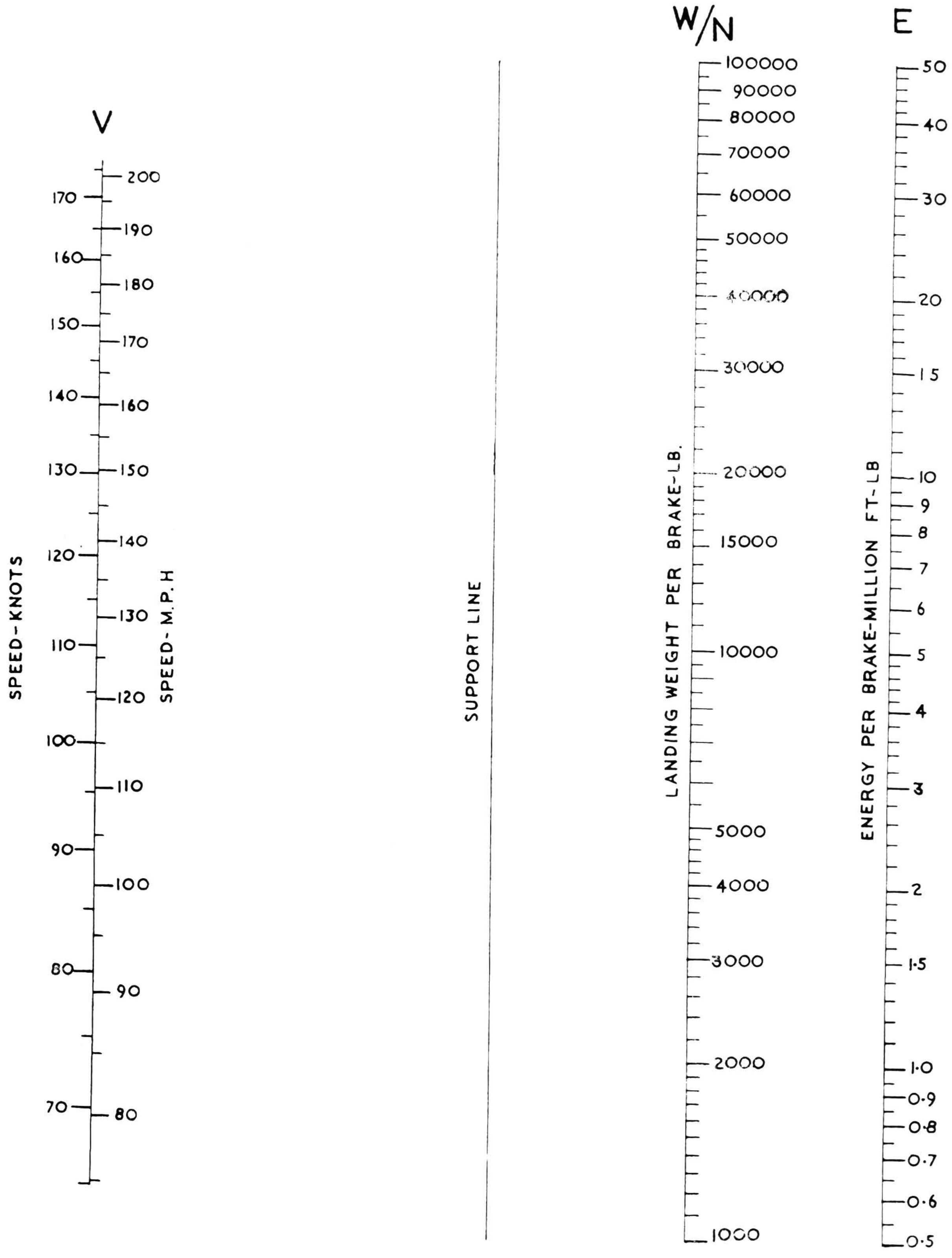
where:—

K = Percentage energy passing into brake.

W = landing weight of aircraft– lb.

N = number of brakes.

V = brake application speed. (usually taken as 1.1 times stalling speed).



TYPICAL BRAKE ENERGIES

Aircraft	*Energy per Wheel* 10^6 *ft.-lb.*	*Wheel Dia. Ins.*
Eon, Auster, etc	0.1	6½
Dove	0.75	12
Marathon	1.0	12
Vampire	1.5	13
Meteor IV	3.5	15
Convair Liner	2.3	16
Ambassador	3.7	17
Wayfarer, Viking	2.0	18
Constellation	7.0	20
Hermes V	7.7	21

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Trade Reviews

Under this heading are published from time to time, brief reviews of a selection of the Trade Publications received for notice

Porus-Krome—Good for the life of your engines

[Avio-Diepen N.V., Vliegveld Ypenburg, Ryswijk, Holland]

Porus-Krome is a method of plating the inside of engine cylinders invented by Dr Hendrik van der Horst, who filed his first patent in 1933. Although he formed a company in Holland (Ingeniers-bureau Lemet Chromium) before the War, the inventor escaped to the U.S.A., where he put his process at the disposal of the Allies and it was widely used in aircraft, land and marine engines for the U.S. Forces.

The process is one that deposits a layer of pure chromium (0·05 to 0·50 mm. thick) directly on the running surface of the cylinder at a temperature of only 70 deg. C. A very complete bond of metals is claimed and, in particular, the porous nature of the deposit overcomes the normal difficulties of lubricating the dense chrome metal, which does not hold oil well. The cost of reconditioning a typical aero-engine cylinder, including grinding out ovality, plating and hone finishing, is only about seven pounds sterling, so that the saving is considerable. The process is fully approved by the American aeronautical authorities and is also being used by the French and Spanish air forces. The European aviation interests are handled by Avio-Diepen, who issued this well-written and informative booklet.

Bearing Lubrication

[C. C. Wakefield & Co. Ltd., Grosvenor Street, London, W.1. 21*s*.]

This handsome quarto book of some hundred and thirty pages is one of a series of technical volumes issued by the makers of Castrol oils. It is very far from being an advertising brochure and is, in fact, a practical textbook, the contents of which were prepared by the Technical Information Department as a result of the work of the firm's Research Laboratories. Moreover, as the authors explain, the question of good lubrication is not only the choice of the right medium, but is also a matter of designing the bearing correctly—fundamentally, there is no substitute for good bearing design. Because of this, the text starts with a discussion of friction and the first principles of lubrication, going on to develop clearly and logically the behaviour of lubricants in use and the various types of bearing, their applications and their particular requirements in lubrication. The book ends with a chapter on the troubles of lubricating systems and bearings and gives some selected remedies. There are 164 illustrations, many of them printed in two colours, that have been very well chosen to amplify the text. It should be made clear that much of the specific material on bearing design deals with industrial machinery; nevertheless, it is an invaluable book and one which, despite its price, we strongly recommend for the library of every engineer.

Paris and Le Bourget 1951

(*Concluded from p.* 227)

the mixture ignites from the sparking plug and the cycle starts. In the veent of a false start fuel and ignition are turned off and the air is blown steadily into the engine to evaporate and disperse any accumulation of fuel. The pilot's controls consist of individual ignition switches and fuel pressure cocks—there are no throttles. Power variation in flight on the Emouchet gliders at present used for flight testing is on the 'blip' principle once used on the old rotary engines. Since the Escopette is mounted in batteries of four or six, a further power control can be obtained by cutting out pairs of engines.

The Escopette weighs 4·8 kg., to which must be added the weight of the air bottle and the auxiliaries, and gives a thrust of 3 to 10 kg. for a consumption of 2 to 5 gm./sec.—that is, 1·8 to 2·4 kg./kg. thrust/hr. a very poor return. Thrust variation with speed is almost linear from 10 kg. at 8 m./sec. to 6·5 kg. at 48 m./sec. When mounted together the interaction of the jets reduces output by some 10 per cent.

Very broadly, the apparent operation of the cycle is that the air entering the combustion chamber from the intake tube is expanded very rapidly and, at the same time, is mixed with the fuel and burns very quickly. Most of the gases must go down the 'waist' pipe—it is three or four times the cross-sectional area of the air intake—which increases their velocity until they are expanded through the nozzle. The amount of gas blowing forward through the air intake tube is small, but such as there is, is collected by the recuperator and partly ejected, partly sucked rearward through the curved pipe. One imagines that the dimensions are critical in order to evacuate completely the burnt charge before sucking in the next at the comparatively high frequency at which the pulses occur.

Owing to its size, its poor aerodynamic shape, and the need to mount it externally, there does not seem much future for the Escopette in its present form, even for guided missiles, despite its simplicity and cheapness.

In 1949 **Turbomeca** showed several small, untried turbine engines, today their products are well known. Their chief engineer, M. Szydlowski has been working on the design of compressors since 1928 and before the War he had made superchargers for several French aero-engines, including a production model for Hispano Suiza. In 1941 he started work on gas turbines in unoccupied France, using trucks as test beds for his prototypes. Then, in 1943, he moved into Spain after the Germans had occupied the whole of France. After the War, work progressed slowly, mainly because of lack of funds, but now these small jet engines are receiving a great deal of attention. M. Szydlowski claims that periods of over 1,000 hours running without overhaul have been achieved and that he sees no reason why 5,000 and even 30,000 hours could not be reached.

The Turbomeca gas turbine cycle is a high speed one with a maximum of 35,000 r.p.m. and, because of this, much of the initial trouble came from bearing failures, so that in the end the firm had to design its own roller bearings. The principle of this cycle is the use of a rotary fuel distributor and combustion chamber to ensure perfect turbulence and to eliminate troublesome jets. Air enters the engine, FIG. 32, through an annular intake and is compressed by a centrifugal fan (giving a compression ratio of 3·8:1) and is then turned through ninety degrees, first, by a series of radial and, second, by a row of axial diffuser vanes into the annular combustion-chamber casing. Attached to the engine shaft, and mounted just behind the fan, is the combustion-chamber shell. This is a curiously shaped 'pot' consisting of inner and outer shells variously perforated to admit air from the main casing: by a series of simple holes, by inwardly projecting tubes and by holes in its inner skin to which cooling air is taken by aerofoil-section ducts running radially across the combustion zone. All this is designed to introduce the air as turbulently as possible and also to keep down the wall temperature of the chamber. Fuel, supplied by a pump on the front of the engine, is introduced through the hollow engine shaft to a distributor casting which has a series of comparatively large bore (about 1/8 in. diam. on the Piméné) radial holes. The pump meters the fuel and the turbulence of the combustion chamber does the rest. A normal turbine wheel is mounted at the rear of the shaft, with a fixed-cone outlet nozzle.

The system is relatively simple, but the evolution of the best combustion chamber form must have been a long and difficult task. The results are good, giving specific consumptions of less than 1·1 kg./kg. thrust/hr., but one doubts whether the principle could be applied to high-power engines because of the increase in diameter. There are, however, many applications of the present range of engines, both as power units for small aeroplanes and as auxiliary power units.

Some of the data for the present Turbomeca range are as follows:

Orédon auxiliary power unit: max. power 160 cv., max. continuous 140 cv.; drives 400 cycle 35 K.V.A. alternator at 6,000 r.p.m. from sea level to 12,000 m.; weight 84 kg.; height 520 mm., width 350 mm., length 878 mm.

Artouste, auxiliary power unit: max. power 275 cv., max. continuous 230 cv.; drives 400 cycle 35 K.V.A. alternator from sea-level to 15,000 m.; weight 127 kg., with alternator.

Piméné: take-off thrust 100 kg. (consumption 1·10 kg./kg./hr.); max. continuous thrust 80 kg. (consumption 1·08 kg./kg./hr.); weight, with electric starter, 63 kg.; dia. 408 mm., length 1,098 mm.

Palas: take-off thrust 150 kg. (consumption 1·2 kg./kg./hr.), max. continuous thrust 120 kg. (consumption 1·13 kg./kg./hr.); weight, with starter, 67 kg.; length 1,114 mm.

Marboré I: take-off thrust 300 kg. (consumption 1·1 kg./kg./hr.), max. continuous thrust 240 kg. (consumption 1.05 kg./kg./hr.); weight, with starter, 130 kg.; dia. 567 mm., length 1,333 mm. The Marboré II, for the same weight, gives 380/300 kg. thrust with consumptions of 1·15 and 1·12 kg./kg./hr. respectively.

Two interesting developments are the Aspin I and II 'double-flux' engines in which a ducted fan is used to by-pass air to the jet stream. For a weight of 145 kg. the latter gives 360/300 kg. thrust at consumptions of only 0·55 and 0·52 kg./kg./hr. respectively. The diameter of this unit is about 720 mm. Altogether a remarkable achievement.

There are also several applications of the engines for driving cabin blowers—where the good altitude performance is of particular value—and as combination accessory and air-conditioning units.

Conclusion

We originally intended to deal with two or three of the components and accessories that were of outstanding interest, but space does not permit of this. We intend, however, to describe some novel navigational instruments next month.

One feels that the Salon this year was not so lightly to be dismissed as many would have it. It was well supported by Great Britain, by the U.S.A., Italy and the Netherlands, when one takes into account the security restrictions and the currency regulations which limit markets today. As a weather vane for the French industry it was accurate. Slow development by the nationalized companies was shown by their empty stands, which also indicated a more realistic approach than did the manifold prototypes of the past. Imaginative, if impecunious, efforts by the smaller firms were mainly along useful lines of development. Slow progress with production of the sound but unspectacular Ouragan; a lingering faith in the overloaded and fantastic Espadon; and the absence of the experimental Grognard, of which there are two, and the SO-4000 pointed at manifest weakness and lack of energy in the policies of the Ministère de l'Air. Nevertheless, as we hope the preceding pages have shown, the French industry is yet capable of much that is good in the design of aircraft and engines.

JAMES HAY STEVENS

CORRESPONDENCE

(*Concluded from p.* 238)

sions when the efficiency may be expected to be low:

(*a*) At high altitudes, where v is large.

(*b*) When the pipe is very small.

The first case is of most practical importance, showing that the choking velocity in a turbine nozzle is less at altitude than at ground level. The second case is easier to verify by experiment.

The dependence of the velocity of sound on the frequency introduces dispersion into a disturbance such as a shock wave which contains many frequency components. This is analogous to the dispersion of light in a refracting medium.

J. M. STEPHENSON

Farnborough, Hants

REFERENCES TO LITERATURE

(1) Naylor, V. D., AIRCRAFT ENGINEERING, XXIII, p. 160, June 1951.

(2) Rayleigh, Lord, *Theory of Sound*, p. 285, 1877.

(3) *Op cit.*, p. 287.

(4) Kaye, G. W. C., and Sherratt, G. G., *Proc. Roy. Soc.*, 141, p. 123, 1933.

CANADIAN RESEARCH

(*Concluded from p.* 243)

port Board. The Committee has already held its first meeting, with Dr C. J. Mackenzie appointed as the Chairman. A Technical Advisory Panel of Deputies under the National Aeronautical Research Committee will be responsible for the consideration of technical matters involving policy and will serve as an advisory panel to the Director of the Establishment. This panel will be composed of the Director of the Establishment; the Chief of Division (B) of the Defence Research Board, who is also the Scientific Adviser to the Chief of Air Staff; the Air Member for Technical Services of the R.C.A.F., and the Chief Aeronautical Engineer of the Department of Transport.

The development of the Ottawa aerodrome at Uplands has already commenced. Sufficient land was acquired by the Government to meet any reasonable future requirement and construction of the new aerodrome is in hand. It is planned this year to provide two runways 200 feet wide, one of which will be 8,800 feet long and the other will be 6,000 feet. The design of the flight research facilities is nearing completion and it is hoped that construction will be commenced early this summer. A concrete arch hangar is planned, with administrative, laboratory and workshop facilities integral with the hangar and extending around three of its sides. A heating plant, a storage and motor transport building and a cafeteria will complete the first stage of the Flight Research Unit, with occupancy planned for the summer of 1952. As the need for new research equipment or new laboratories develops, these will be located, whenever practicable, on the new site at Uplands, where sufficient land is available for development over the years of an aeronautical research centre which can meet the major requirements of Canadian aviation.

Correspondence should be addressed to the Director, National Aeronautical Establishment, Montreal Road, Ottawa, Canada.

Trade Announcements

A monthly feature giving news of recent Government and professional appointments, industrial developments and business changes, etc.

Accurate Recording Instrument Company's Extension

The Accurate Recording Instrument Company opened a new extension of 4,500 sq. ft. at their works in Garth Road, Morden, Surrey, on June 1. This has been rendered necessary by the rapidly increasing demand for their products, both from the home and export markets.

Bristol's New Director

Mr A. E. Russell, B.Sc., F.R.Ae.S., F.I.Ae.S., Chief Designer of the Aircraft Division of the Bristol Aeroplane Co. Ltd., Filton, Bristol, has been elected to the Board of the Company.

B.W.R.A. Appointments

The British Welding Research Association, of 29 Park Crescent, W.1, announces that Mr Nicol Gross, Ph.D.(Cantab.), A.M.I.Mech.E., Member, A.S.M.E., has been appointed Assistant Director of Research. Dr Gross will continue his responsibility for the Association's engineering researches and will remain in charge of the Research Station at Abington.

Mr K. Winterton, Ph.D., B.Sc., and Mr H. E. Dixon, M.Sc., A.I.M., have been appointed Chief Metallurgists, the former for ferrous metals, and the latter for non-ferrous metals.

Mr C. L. M. Cottrell, M.Sc., and Mr P. T. Houldcroft, B.Sc., have been appointed Assistant Chief Metallurgists for ferrous and non-ferrous metals respectively.

F. J. Edwards in Birmingham

Correlative with their showrooms at 359-61 Euston Road, and the Machine Centre, Liverpool Road, London, N.1, F. J. Edwards Ltd. have opened a new warehouse in James Street, Birmingham, 3.

Here stocks of sheet metal working machinery; presses and machine tools will be displayed and technical representatives will be available for consultation.

Fairey's New Chief Engineer

It is announced that Mr R. L. Lickley, B.Sc., D.I.C., M.I.Mech.E., F.R.Ae.S., is joining the Fairey Aviation Co. Ltd., of Hayes, Middlesex, as Chief Engineer. Since 1946 he has been Professor of Aircraft Design and Deputy Principal of the College of Aeronautics, Cranfield.

Folland Aircraft Company's Managing Director

The Board of Folland Aircraft Ltd., of Hamble, Hants, announce that Mr H. P. Folland, O.B.E., F.R.Ae.S., M.I.Ae.E., F.R.S.A., F.I.Ae.S., has relinquished his appointment as Managing Director of the Company as from June 30, 1951. Mr Folland, who has held the position of Managing Director since June 1, 1937, will continue to serve on the Board of Folland Aircraft Ltd.

Mr W. E. W. Petter, C.B.E., B.A., F.R.Ae.S., who has been Deputy Managing Director since October, 1950, has been appointed Managing Director of the Company as from July 1, 1951.

Foster Switchgear Production

L.D. Holdings, of 25 Shaftesbury Avenue, W.1, announce that increasing demand for Foster transformers, voltage regulators, specialized test equipment and H.I. switchgear, has made it impossible to deal with the greatly increased volume of orders at the Wimbledon factory of Foster Transformers & Switchgear Ltd. (a company in the Lancashire Dynamo group). To cope with this situation, therefore, arrangements have been made to transfer production of Foster Switchgear to Crypton Equipment Ltd. another factory in the Lancashire Dynamo Organization. The Crypton factory at Bridgwater, Somerset, newly built, on a seven-acre site, can provide the increased production space which these developments demand and can also offer scope for factory extensions.

Hawker's General Manager

Mr A. Neville Spriggs, O.B.E., has neen made General Manager of Hawker Aircraft Limited. The firm has acquired the Squires Gate shadow factory near Blackpool for the production of jet fighters, and Mr Spriggs will be dividing his time between Blackpool and Kingston.

He was appointed Deputy General Manager in 1942 and to the Board in 1945.

I.Ae.S. Awards

The Institute of the Aeronautical Sciences, 2 East 64th Street, New York, 21, U.S.A., announce the following awards:

Dr John Burlin Johnson, head of the Metallurgy Group, office of Air Research at the Cook Field, Dayton, Ohio, receives the Thurman H. Bane Award, given annually to an officer or civilian of the Air National Command for outstanding achievement in aeronautical development.

Lt-Col Marion Eugene Carl, U.S.M.C., commanding the Carrier Aircraft Section, Flight Test Division Naval Air Test Centre, Paluscent River, receives the Octave Chanute Medal, presented annually for a notable contribution made by a pilot to the aeronautical sciences.

Insley (London) Ltd.

A considerable range of ball, roller and needle bearings now in short supply will become available for early delivery to users in the United Kingdom and Commonwealth following arrangements made by Mr L. Insley, Managing Director of Insley (London) Ltd., 119 Oxford Street, London, W.1, during a recent visit to Switzerland.

Insley (London) Ltd. have been appointed sole distributors for Hydrel Needle Bearings, manufactured by Hydrel AG., Romanshorn, Switzerland.

The company have also obtained the agency for KFA Kugellager-Fabrik Arbon AG., leading Swiss manufacturers of ball and roller bearings, taper and needle roller bearings, rollers and super-precision bearings.

I.A.T.A. Technical Committee Chairman

Captain J. C. Kelly-Rogers, of Dublin, one of the pioneers of the trans-Atlantic airline routes, has been elected chairman of the International Air Transport Association (I.A.T.A.) Technical Committee, which deals with a large range of flying matters on behalf of the world's airlines.

Captain Kelly-Rogers, who is Assistant General Manager (Technical) of Aer Lingus, succeeds J. T. Dyment, Director of Engineering, Trans Canada Air Lines, Montreal. He will take office after the Annual General Meeting of I.A.T.A. at London in September.

Newly-elected vice-presidents of the I.A.T.A Technical Committee are Paul Goldsborough, Kansas City, Mo., Director of Communications, Trans World Airlines, and Geoffrey de Meiss, Zurich, Technical Director of Swissair.

New E. H. Jones Agency

E. H. Jones (Machine Tools) Ltd., announce that they have been appointed agents for Great Britain and Eire for the range of A-1 machine tools produced by Netherlands Engineering Works 'Artillerie-Inrichtingen' Ltd., of Hembrug, Zaandam, Netherlands.

Ministry of Supply European Offices

The opening of two of the four main European offices of the newly-formed European Purchasing Commission, was announced by the Ministry of Supply recently.

The directors of these offices, which will be opened on June 1, and their addresses are: **Belgium:** Mr Norman W. Doley, 107 Rue Belliard, Brussels. **Germany:** Mr A. S. Radford, 5 Mehlemer Strasse, Marienburg, Cologne.

Monochrome—Van der Horst Alliance

An agreement has been reached between the Birmingham Small Arms Co. Ltd., on behalf of their subsidiary, Monochrome Limited, of Redditch, and the Van der Horst Company of Holland, by which each company will be able to use either of their two proprietary processes of hard-chromium plating cylinder liners. Messrs Van der Horst are thus enabled to operate the Monochrome 'Honeychrome' process in Holland, and Messrs Monochrome the Van der Horst 'Porus Krome' process in the United Kingdom.

Samuel Osborn's New Director

Mr I. G. Buchan, C.A., has been appointed Chief Accountant and Local Director of Samuel Osborn & Co. Limited, of Clyde Steel Works, Sheffield. Mr Buchan took up his appointment in May after five years on the staff of Thomas McLintock & Co. Ltd., of London.

Percival Aircraft Limited

The appointment as Technical Director to the Board of Percival Aircraft Limited, of Luton, Beds, of Mr Leslie George Frise, B.Sc., F.R.Ae.S., A.F.I.Ae.S., is announced.

Mr Leslie Frise has been Chief Engineer and Chief Designer of Percival Aircraft Limited for nearly three years. Before this he held similar posts for many years with the Bristol Aeroplane Company.

Plessey's New Director

The Plessey Company Limited, of Ilford, Essex, announce that under Article 97a of the Company's Articles of Association, the Board of Directors has appointed the following to be Executive Directors of the Company: Mr John A. Clark, Mr Michael W. Clark, Mr G. C. Gaut, Mr A. E. Underwood, and Mr T. White Wilson.

Mr T. White Wilson has been appointed the first Chairman of the Executive Directors.

Stordy Engineering Ltd. Move

Stordy Engineering Ltd., thermal and mechanical engineers, manufacturers of furnaces, industrial ovens and metal finishing plant, have moved to: Cumbria House, Goldthorn Hill, Wolverhampton. Telephone: Wolverhampton 37341-2.

Wickman Limited

A. C. Wickman Ltd., of Coventry, announce that on June 28, 1951, the name of the Company was changed to Wickman Limited.

BOOKS RECEIVED

All books received from publishers are listed under this heading. Extended reviews of a selection appear later. Inclusion in this list, therefore, neither precludes, nor implies, in any particular instance, further notice.

Air Mileage Handbook 1951. Loose-leaf binding, 109 pages. [International Air Radio Ltd., Hayes Road, Southall. 42*s.*]

An Introduction to Servo-Mechanisms. A. Porter. 154 pages illustrated. [Methuen. 7*s.* 6*d.*]

Press Tool Practice. P. S. Houghton. 257 pages, illustrated. [Chapman & Hall. 21*s.*]

Theory of the Interior Ballistics of Guns. J. Corner. 443 pages, illustrated. [John Wiley & Sons, New York (Chapman & Hall). 64*s.*]

Program. Paper bound. 111 pages. [Air Navigation Development Board, Civil Aeronautics Administration, Washington 25, D.C., U.S.A. Free.]

Lubrication, Its Principles and Practice. A. G. M. Michell. 317 pages, illustrated. [Blackie. 35*s.*]

Society of Aeronautical Students 'Leonardo da Vinci' Annual Report 1949-1950. Booklet. [Secretary, Kanaalstraat 10, Delft, Netherlands, Free.]

The Newspaper Press Directory 1951. Centennial issue. 601 pp. [Benn Brothers. 42*s.*]

Standard Methods of Analysis of Iron, Steel and Ferro-Alloys. Fourth Edition. 169 pp., illustrated. [The United Steel Companies Ltd., P.O. Box 64, Sheffield. 17*s.* 6*d.*]

Shawcross and Beaumont on Air Law. Second Edition. 1,378 pp. [Butterworth. 126*s.*]

Physics of Lubrication. 96 pp., illustrated. [The Institute of Physics, 47 Belgrave Square, S.W.1. 15*s.*]

Newnes Engineer's Reference Book 1951. Edited by F. J. Camm. 1,725 pp., illustrated. [George Newnes. 50*s.*]

Electricity as an Aid to Production. Paper bound, 52 pp., illustrated. [The Institution of Electrical Engineers, Savoy Place, W.C.2. 6*s.*]

Structural Plastics. H. C. Engel, C. B. Hemming and H. R. Merriman. 301 pp., illustrated. [McGraw-Hill. 38*s.* 6*d.*]

Technical Reference Book of Compressed Air Terms and Standards. Paper bound, 91 pp., illustrated. [The British Compressed Air Society, 94-98 Petty France, S.W.1. 10*s.* 6*d.*]

The Aeroplane Directory of British Aviation. 1951 Edition 689 pp. [Temple Press. 15*s.*]

Month in the Patent Office

These abstracts of British Patent Specifications are taken, by permission, from the officially prepared abridgments classified in Groups. Sets of Group abridgments can be obtained from the Patent Office, 25 Southampton Buildings, W.C.2, sheet by sheet as issued, at a subscription of 10s. per Group. Copies of the full specifications are obtainable at the same address, price 1s. each

610,620. Thick aerofoil sections; boundary layer control. S. Goldstein and E. J. Richards. April 11, 1946, No. 11195. (Class 4.)

An aerofoil is provided on one or each of its surfaces with a boundary layer suction slot located nearer the trailing than the leading edge, the aerofoil section being so shaped that, at all incidences within a prescribed range, the calculated potential flow velocity distribution along the section or each slot-containing surface is such as not to provoke boundary layer separation, except at a position coinciding with or closely adjacent the slot, at which position an abrupt decrease of velocity in the downstream direction occurs. The invention is intended for application to very thick aerofoil sections giving low drag at low lift coefficients. FIG. 1 shows a symmetrical section, particulars of the co-ordinates of which are given in the Specification, having a thickness/chord ratio of 30 per cent. and in which suction slots S1, S2 on the upper and lower surfaces, located at 80 per cent of the chord from the leading edge, are connected to a suction pump P by ducting D. The calculated velocity distribution is shown in FIG. 2, curve 1 applying to both surfaces at zero incidence, curves 2, 3 and 4 to the upper surface at increasing angles of incidence, and curves 5 and 6 to the lower surfaces, in all cases a discontinuity occurring in the velocity curve at a point 80 per cent. of the chord from the leading edge. FIG. 3 shows an unsymmetrical section having a thickness/chord ratio of 31·5 per cent., and in which a suction slot S3 is provided on the upper surface at 69·11 per cent of the chord from the leading edge. The slots may face forwardly or rearwardly. Specification 578,763 is referred to.

FIG. 1.

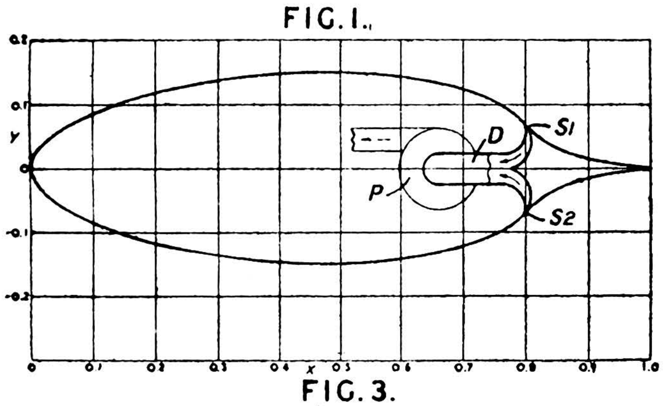


FIG. 3.

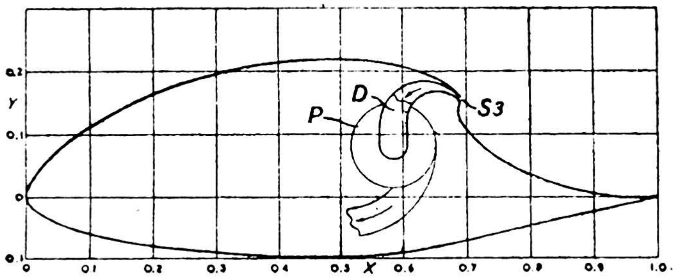


FIG. 2.

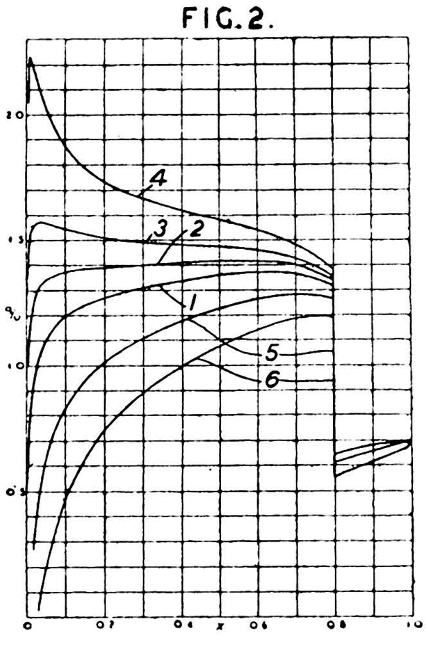


FIG. 1.

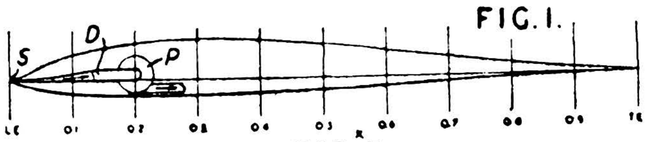


FIG. 5.

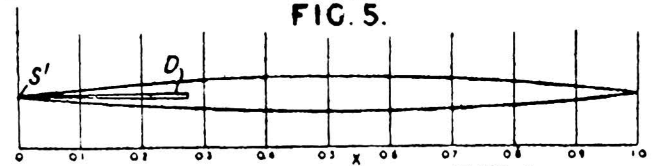
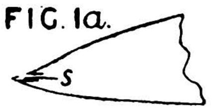


FIG. 1a.



Specification 610,621

610,621. Aerofoils; boundary layer control. S. Goldstein and E. J. Richards. April 11, 1946, No. 11196. (Class 4.)

An aerofoil of small or moderate thickness/chord ratio, and of which the leading edge is sharp or of small radius, is provided with a sharp-edged spanwise suction slot at or very close to the leading edge for applying suction to the boundary layer. FIGS. 1 and 1*a* show an aerofoil with a thickness/chord of ratio 8·6 per cent with a sharp leading edge, the extreme tip of which is truncated by a forwardly facing suction slot S, the width of which is 0·4 per cent. of the chord. The slot is connected to a suction pump P through a duct D. A thin symmetrical aerofoil suitable for flight at supersonic speeds is shown in FIG. 5, the thickness/chord ratio being 5·4 per cent, and the width of the suction slot S^1 is 0·26 per cent of the chord. Specification 578,763 is referred to.

610,622. Reducing surface friction; boundary layer control. J. H. Preston and B. Thwaites. April 11, 1946, No. 11197. (Class 4.)

Separation of the boundary layer of a fluid stream moving over a solid surface is prevented by forming the surface of porous material, the linear size and spacing of whose pores are small compared with the thickness of the fluid boundary layer, means being provided for applying suction to the fluid through the pores of the material. The pore size and spacing are of the order of one-hundredth of the boundary layer thickness and do not exceed one-fiftieth thereof. The invention may be applied to aerofoils, propeller blades, blading for fans, compressors or turbines, aircraft bodies, engine nacelles, submarine hulls, or ducts or channels in which fluid flow is confined, such as diffusers for compressors and pumps, or the walls of wind tunnels. Suitable surface materials are sintered metal sheet or fine metal gauze bent to the desired shape, or a mould of the desired form may be sprayed to produce a porous metal layer. FIG. 1 shows a thick-section symmetrical aerofoil in which the upper and lower surfaces 5 of the rearward quarter-chord are of finely porous material, a space 6 being formed below the porous covering by an internal partition 7, the space being connected to a suction pump P by ducts D. In the embodiment according to FIG. 3, the porous surface layer 12 extends between the points 10 and 11 at the leading edge of a thin symmetrical aerofoil. In order to preserve laminar flow, the porous areas of the surfaces of the aerofoils may be more extensive than illustrated, and an aerofoil may even be provided with a porous surface throughout. FIG. 5 shows a symmetrical rectangular-section channel or duct in which the portions S of the walls W over which the velocity gradient is steeply negative are of porous material, to which suction is applied. Variation of the applied suction head may be obtained by partitioning the space below the porous area and applying different heads to the several compartments, or the degree of porosity of the surface material may be varied appropriately. Specification 479,598 is referred to, and the Provisional Specification refers to Specification 578,763.

FIG. 1.

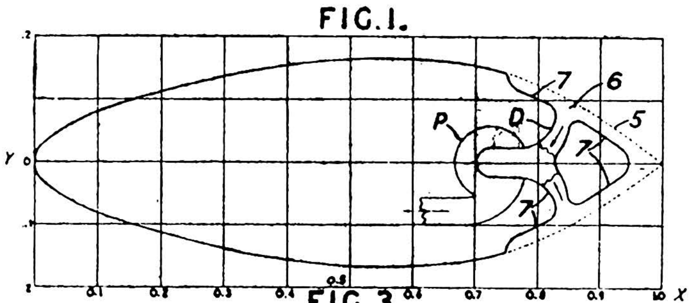


FIG. 3.

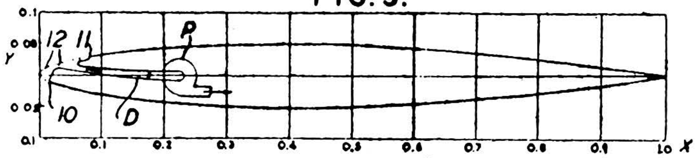
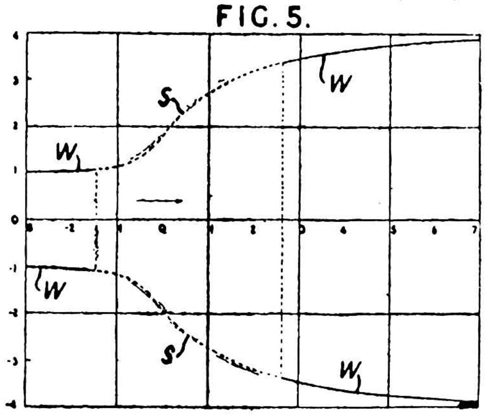


FIG. 5.



Specifications 610,620 left, 610,622 right

610,623. Boundary layer control. S. Goldstein, E. J. Richards and J. H. Preston. April 11, 1946, No. 11198. (Class 4.)

A solid surface intended to serve as the boundary of a fluid stream is provided with a transversely-extending slot facing downstream through which fluid may be injected downstream into the boundary layer tangentially of the surface, which is so shaped that the calculated potential flow velocity decreases abruptly in the downstream direction at a position substantially coincident with the slot and not upstream of it, the upstream velocity gradients being such as not to provoke boundary layer separation, means being provided for injecting fluid through the slot into the boundary layer at a velocity not less than that of the outside edge of the boundary layer immediately upstream of the slot. FIG. 4 shows a thick unsymmetrical aerofoil, the section of which is shaped to produce a discontinuity in the velocity distribution over the upper surface at a point 69·1 per cent. of the chord from the leading edge, where a spanwise slot S is provided, connected to a pump P for injecting air into the boundary layer. The symmetrical aerofoil section shown in FIG. 6 is shaped to produce velocity discontinuities at points on the upper and lower surfaces distant 80 per cent. of the chord from the leading edge. Slots S1, S2, in communication with a pump P are located at these points, the upper one S1 being a suction slot and the lower one S2 a discharge

(Continued overleaf)

FIG. 4.

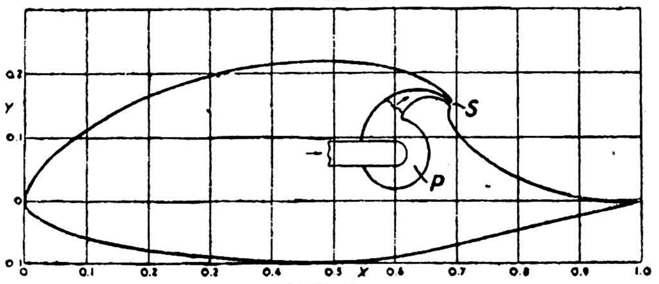


FIG. 6.

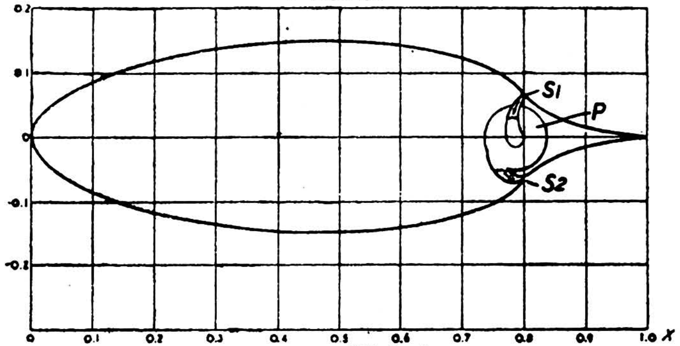
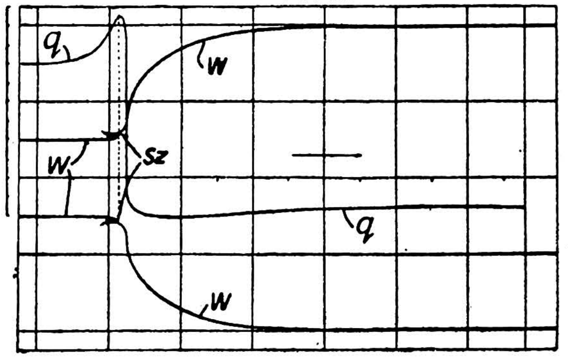


FIG. 8.

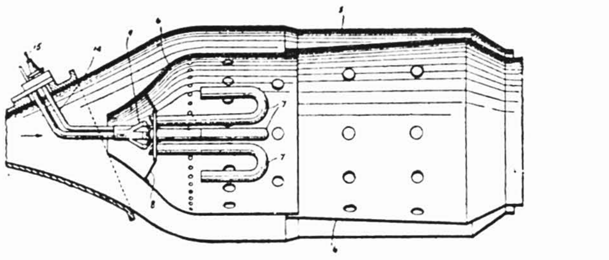


Specification 610,623

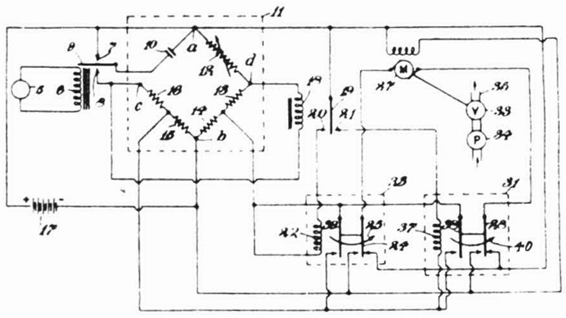
U.S. Patent Specifications

These details and drawings of patents granted in the United States are taken, by permission of the Department of Commerce, from the 'Official Gazette of the United States Patent Office'. Printed copies of the full specifications can be obtained, price 10 cents each, from the Commissioner of Patents, Washington, D.C., U.S.A. They are usually available for inspection at the British Patent Office, Southampton Buildings, Chancery Lane, London, W.C.2.

2,541,900. Multiple Fuel Jet Burner and Torch Igniter Unit with Fuel Vaporizing Tubes. Frederick D. M. Williams, Nobel, Ontario, Canada, assignor to A. V. Roe Canada Limited, Malton, Ontario, Canada, a corporation. Application December 24, 1948. Serial No. 67,118. 5 Claims. (Cl. 60—44.)



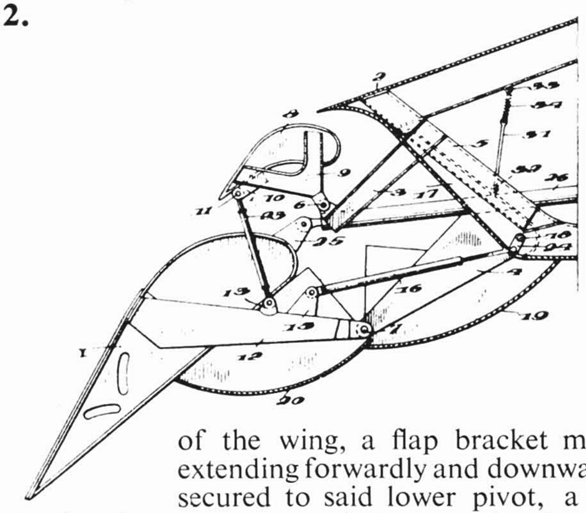
In a combustion chamber of a gas turbine engine, a flame tube in which combustion takes place, openings in the flame tube for admitting a stream of air at one end of the flame tube to support combustion, vaporizer tubes mounted in the flame tube adjacent the upstream end of the flame tube and extending longitudinally thereof, each such vaporizer tube having an inlet end exposed to the air stream through the combustion chamber and an outlet end discharging into the flame tube, and an injector head located substantially on the longitudinal axis of the flame tube at its upstream end, said injector head comprising an igniter jet directed into the flame tube substantially at the longitudinal axis thereof between the vaporizer tubes, whereby an igniting flame may be injected directly into the flame tube and played upon the vaporizer tubes, an igniter situated in front of said jet, a plurality of fuel supply jets arranged around the igniter jet and directed to the inlet ends of the vaporizer tubes, a fuel inlet conduit for the fuel supply jets, and a fuel inlet conduit for the igniter jet within and substantially co-axial with the fuel inlet conduit for the fuel supply jets.



2,542,499. Automatic Control for Gas Turbines. Peter Fortescue, Bristol, England, assignor to The British Aeroplane Company Limited, Bristol, England, a British company. Application October 29, 1946. Serial No. 706,317. In Great Britain October 16, 1945. 5 Claims. (Cl. 175—355.)

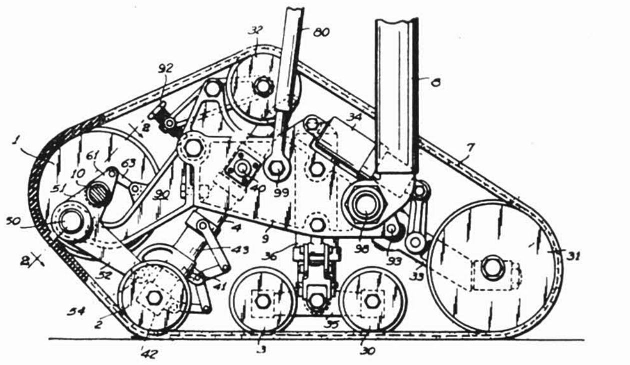
Apparatus for automatically controlling a gas-turbine engine in which an operating variable of the engine is electrically controlled comprising a bridge network, means for applying an electrical quantity, proportional to the engine variable, to the network, means for applying a standard electrical quantity representing the datum value which the variable ought to have, said quantities being compared in the network so that an electrical quantity results from said comparison when the network is unbalanced, control means to which said resultant electrical quantity is applied to adjust the engine variable and means actuated by the resultant electrical quantity for increasing the unbalanced state of the network.

2,542,792. Aeroplane Wing Flap and Slat Mounting. James H. Bennett, Baltimore, and James A. Webb, Essex, Md., assignors to The Glenn L. Martin Company, Middle River, Md., a corporation of Maryland. Application August 16, 1947. Serial No. 769,002. 5 Claims. (Cl. 244—42.)



An aeroplane wing flap mounting comprising a plurality of bracket means rigidly affixed on the trailing edge of an aeroplane wing extending downwardly and to the rear thereof, each of said bracket means supporting an upper and lower pivot, said upper pivot being located within the wing profile and said lower pivot being located below the under side of the wing, a flap bracket means extending forwardly and downwardly secured to said lower pivot, a slat having bracket means secured thereto extending forwardly and downwardly from the leading edge thereof supported on said upper pivot, linkage means pivoted at a point on said slat adjacent the trailing edge thereof, and a point on said flap adjacent the nose portion thereof to control the incidence of said slat as the flap is moved to a position of high lift or drag, a two-part streamline housing faired around the portions of said brackets extending below the lower surface of said wing, one portion of said housing secured to said wing structure and the other portion of said housing secured to said flap.

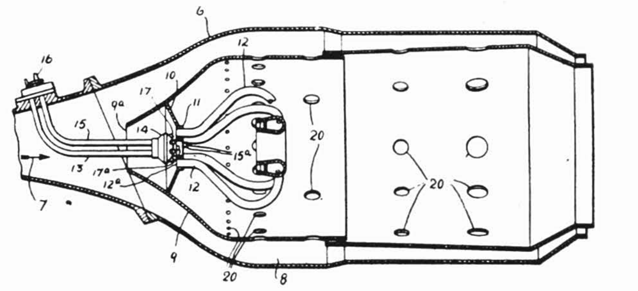
2,544,985. Track-type Landing Gear. George T. Drakeley and Donald W. Finlay, Seattle, Wash., assignors to Boeing Airplane Company, Seattle, Wash., a corporation of Delaware. Application July 11, 1949.



A track-type landing gear comprising an endless track band, a frame, a front bogie wheel, a braking wheel ahead thereof and elevated thereabove, a rear wheel, additional bogie wheels intermediate the front bogie wheel and the rear wheel, an upper wheel supported from the frame, resiliently yieldable means supporting all wheels except the upper wheel from the frame and arranged in a pattern, including the upper wheel, to receive and guide said track band and to maintain it, between the front bogie wheel and the rear wheel, in ground contact while the landing gear is ground-borne; a support carried by and for movement relative to the frame, and constituting the immediate support of said braking wheel, said support being operatively connected for movement with the front bogie wheel, relative to the frame; brake reaction means carried by said support and anchored to said frame; and brake means reacting between said brake reaction means and said braking wheel.

2,548,087. Vaporizer System for Combustion Chambers. Frederick Denison Morgan Williams, Nobel, Ontario, Canada, assignor to A. V. Roe Canada Limited, Malton, Ontario, Canada. Application January 21, 1950.

In a vaporizer system for a combustion chamber in which liquid fuel is burned in an air stream flowing in the combustion chamber, vaporizer tubes having inlet ends and outlet ends, said tubes being secured with their inlet ends facing the air stream and the outlet ends of the tubes converging into a common outlet facing the air stream.



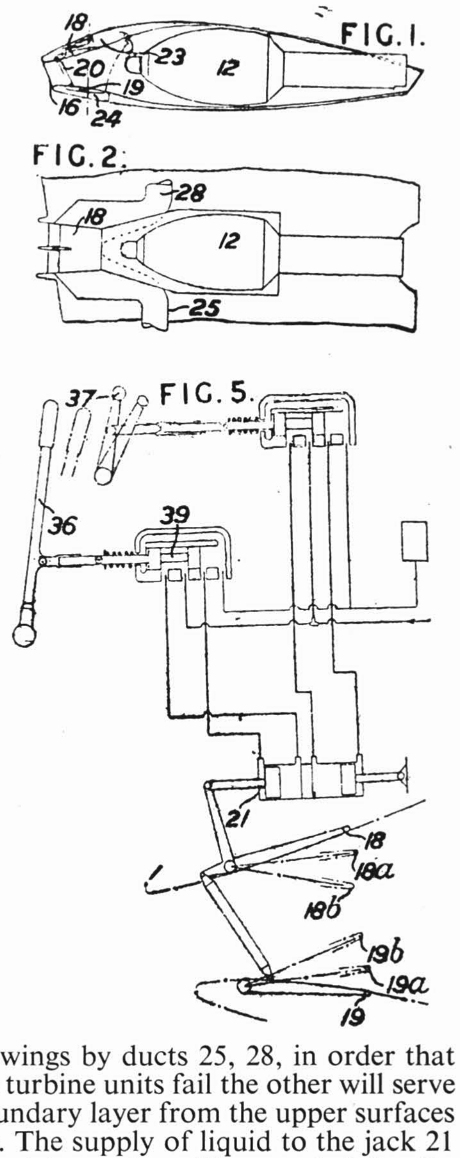
BRITISH PATENTS

(Concluded from previous page)

slot through which air drawn through the upper slot is injected into the boundary layer on the lower surface. This arrangement may be modified by providing a discharge slot on both the upper and lower surfaces, the air being supplied to the slots through a single branched duct or two separate ducts. Fig. 8 shows the application of the invention to a symmetrical expansion duct with decreasing velocity in the downstream direction, e.g. for a compressor diffuser, in which downstream-facing injection slots S2 are provided in the portions of the wall W where the velocity q changes abruptly. Specification 578,763 is referred to.

611,941. Boundary layer control. Armstrong Whitworth Aircraft, Ltd., Sir W. G., J. Lloyd and C. V. Murray. May 13, 1946, No. 14459. (Class 4.)

In order to reduce the tendency for tip stalling, particularly in tailless aircraft with swept-back wings and powered by an internal combustion turbine unit, the turbine intake is arranged along a streamlined passage provided with shutter means normally forming part of the passage wall but movable to a position partially blocking the passage, so as to cause a depression or reduction of pressure therein, the region of the depression being in communication with an opening in the upper surface of the wing, near the tip thereof, whereby air will be drawn in from that portion of the wing surface, partly by the depression and partly by the suction of the power unit, when the shutter is so moved from its normal position. In the form illustrated an aircraft is powered by two turbine units 12, one in each wing, the intake 16 of each being provided with shutter flaps 18, 19 connected by a link 20, and operable by the pilot's main control member 36 and the throttle lever 37 through a hydraulic servo-motor 21. The shutters move to the positions 18a, 19a, Fig. 5, when either of the controls 36, 37 is moved to the fully back position, and to the positions 18b, 19b when both controls are moved back simultaneously. The regions 23, 24 of the intake near the shutters are placed in communication with openings in the upper tip surfaces of the respective wings by ducts 25, 28, in order that should one of the turbine units fail the other will serve to remove the boundary layer from the upper surfaces of both wing tips. The supply of liquid to the jack 21 is controlled by piston valves 39 operated by the control levers 36, 37. In addition to reducing the tendency to tip stalling, the arrangement ensures that the turbines receive sufficient input of air.



Specification No. 611,941