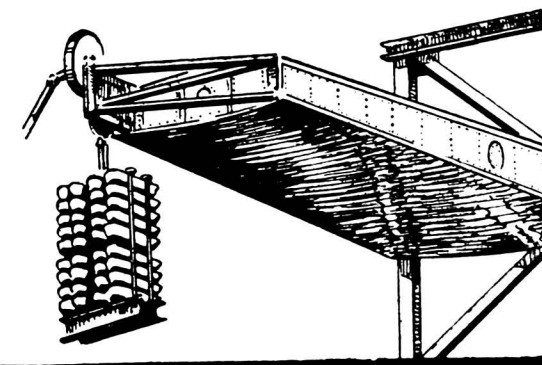
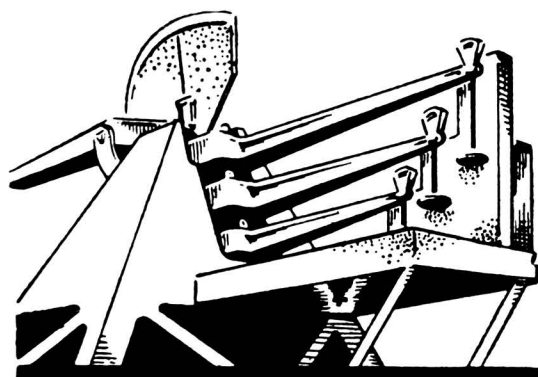


Aircraft Engineering

THE MONTHLY SCIENTIFIC AND TECHNICAL ORGAN
OF THE AERONAUTICAL ENGINEERING PROFESSION



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Food for Thought

AMONG a list of 'preprints', available to those interested, in a recent issue of the *S.A.E. JOURNAL* we noticed the title of one which seemed likely to be of interest to our readers and we therefore wrote to the SOCIETY OF AUTOMOTIVE ENGINEERS for a copy. On receiving it our view was confirmed and we then asked the SOCIETY to be kind enough to let us have the original illustrations—photostats only being attached to the preprint—so that we might reproduce them, since without them the paper would be comparatively speaking meaningless. We duly received these and are now able to publish in this issue the complete paper entitled 'Flight Characteristics at High Mach Numbers'.

So far as we are aware, nothing of precisely the same character has previously appeared in print and we are sure that our readers will agree that it is exceptionally interesting—and indeed highly significant. The volume of results of research work and theoretical investigations conducted into the various aspects of compressible flow, shock waves and all the concomitant phenomena which have been issued must by now be enormous. We tremble, indeed, to think to what almost stratospheric altitudes they would reach if they could be precariously balanced one on top of another. A very large number must be piled up just on the shelves of the editorial sanctum of AIRCRAFT ENGINEERING and we understand that there are in all probability far more that remain carefully guarded in locked cupboards because it is not deemed wise to circulate them, except on a restricted scale, for 'security' reasons. At any rate, our efforts to obtain for publication an article surveying the most up-to-date knowledge on the design of wings for high-speed flight has, on this ground, so far met with no success.

And Yet

Our first reaction to the article, which has been intensified at every fresh reading, was one of—let us not mince words—complete dismay that all the intensive and widespread effort to which we have just referred should have apparently produced so little guidance of direct practical use to the designer of a modern high-speed aeroplane. The impression that surely stands out after a study of this record of development at the flight-testing stage is one of frustration. As MESSRS OUTMAN and GRAFF themselves in their Introduction write, "The many months of intensive design effort on the part of engineers and shop personnel have set the stage for an all-out development, modification and flight test programme which frequently taxes their ingenuity and energy to a far greater degree than did the initial design work." Depressing as these words are we cannot but feel that they are justified by the experiences detailed in the paper.

The most disturbing feature seems to us to be the lack of basic knowledge from which a planned approach to the cure of the various

undesirable phenomena that manifested themselves could be made. It seems to have been only possible to attack each problem as it cropped up by step by step, almost rule-of-thumb, methods. To quote the authors again, "As improvements are made the Machs disappear from one part of the aeroplane and appear in another part"—a truth which is only too clearly confirmed as the story of the various instabilities and roughnesses that developed is unfolded.

Welcome Frankness

In writing thus strongly, we wish to make it absolutely clear that no thought of criticism of the MCDONNELL AIRCRAFT CORPORATION or its design staff is intended. Nothing is further from our minds. We have no doubt whatever that all other designers are finding themselves in the same predicament and the tale of losses of expert test pilots when trying out these modern aeroplanes is the saddest possible evidence of the critical stage we have reached in the design of aeroplanes to fly at Mach numbers approaching unity. Far indeed are we from criticizing the Company concerned. On the contrary, we applaud their courage and public-spiritedness in releasing for the benefit of other workers in the same field so frank and complete an *exposé* of the troubles they encountered and the progress they made in overcoming them. Daunting indeed must the frustrating experiences they met at times have seemed to be. Such a frank laying of their cards on the table is rare indeed—though, as we have remarked on occasion before, less so in America than in England, where there is much greater reluctance to be frank and open about indeterminate experiments; which is a pity as, so frequently, far more is to be learned from them than from the undramatic record of progress and achievement that is all too-frequently handed out for approbation.

We would like to think that experience with this one aeroplane has led to a general increase of knowledge that can be, and is being, used in earlier stages of the development of a later type. Unfortunately, no very great promise of this is held out in the authors' conclusions at the end of their paper; which somewhat pessimistically seem to imply that the same process will have to be gone through when the flight-testing stage of the new aeroplane arrives. It would be interesting if any general lessons that can be learnt from these experiments were revealed.

An Ingenious Mechanism

We thank the INSTITUTION OF MECHANICAL ENGINEERS for permitting us to reproduce the paper on the ingenious Brabazon powerplant. This, delivered at a meeting in London last month, had been previously read before a meeting of the INSTITUTE in Bristol on January 11, 1950. As a matter of history, we had invited a contribution on this subject to AIRCRAFT ENGINEERING some two years ago. We are, therefore, more than glad to welcome its appearance.

The Design and Development of the Twin-Centaurus Power-Plant for the Bristol Brabazon

A Paper presented by J. L. Norton, A.M.I.Mech.E.,* at a General Meeting of the Institution of Mechanical Engineers in London, on Friday, April 20, 1951

Introduction

FOR a non-stop service between London and New York, it was considered that an aircraft of approaching 250,000 lb. all-up weight would be required to carry a payload great enough to ensure an adequate return on the capital expenditure necessary for a stated traffic density.

So large an aircraft required great power for its propulsion and this meant large engines. At the time the Bristol 'Brabazon' design was prepared the only power unit of suitable size appeared to be the Bristol 'Centaurus'. This is an eighteen-cylinder, air-cooled, sleeve-valve radial engine which produces 2,500 h.p. at 2,700 r.p.m. for take-off. A total of eight of these engines was required, and the author was entrusted with the work of engineering the installation of them.

General Considerations

In the design of aircraft, drag must be kept to an absolute minimum: it becomes more critical as the required speed and range increase. Designers of airframes have criticized the engine designer because in normal installations the engine, even though carefully cowled and faired,

Summary

The adaptation of eight 'Centaurus' engines, grouped in pairs, to drive airscrews presenting only four disks to the air stream in the Bristol 'Brabazon' is described, including their submersion within the wing thickness, and special cooling arrangements. The reasons chosen for the lay-out of the power plant are given.

Description of the design of the dual-reduction gear includes the primary and auxiliary drives, freewheels, and propeller shafts. The operating system of the propellers is briefly reviewed.

The plant used and programme for testing, including fire precautions and detection and an actual engine fire test, are described.

forms a large excrescence on the wing, and this results in an appreciable drag loss. As aircraft size increases, engine diameter also increases, but at a lower rate. This is due to several factors, such as the increasing number of engines and the increasing ratio of horse-power to diameter. In the 'Brabazon', the wing thickness is, in fact, greater than the diameter of the engine. It seemed logical, therefore, completely to submerge the engines within the wing profile, and thus avoid the drag associated with the normal nacelle installation.

Eight engines would normally require eight

propellers, but these, spread along the wing leading edge, would not be conducive to aerodynamic efficiency. It was therefore agreed that the engines should be grouped in pairs, each pair driving two co-axial propellers; thus only four propeller disks would be presented to the air stream.

The next consideration was how best to arrange the engines, and the drives to the propellers. Of the numerous possibilities, six different lay-outs received serious consideration (FIG. 1). Each had its advantages and its drawbacks. From the aspect of mechanical design there was a tendency to favour the parallel engine arrangement. On the other hand, since cooling of the engines had to be paid for in terms of power or drag, it was important to keep the air ducting as simple and unrestricted as possible. Therefore it was of advantage to avoid such obstructions in the cooling-air stream as would be caused by large gearboxes, etc.

The weight of the complete power unit would need to be kept to the lowest possible figure so as to maintain the highest possible payload. In regard to weight, every pound saved in airframe or engine-installation weight meant that the operator could carry 1 lb. more payload. It is illuminating to calculate the revenue value, to the aircraft operator, of this saving over a period representing the useful life of the aircraft, say, eight years. Assuming that a passenger plus baggage weighs 250 lb., and that the single London-New York fare is £150 sterling, the cost per pound per trip is £150/250 or twelve shillings. Now a fair figure for aircraft utilization is 3,000 hours per year and the journey distance is 3,443 miles. At 230 m.p.h. average speed this corresponds to 200 single journeys annually. The total revenue which the operator would receive for each pound of passenger weight for the period stated is, therefore, £200 × 8 × (12/20) £960, say, £1,000 in round figures.

* Special Projects Engineer, The Bristol Aeroplane Company, Ltd. (Engine Division).

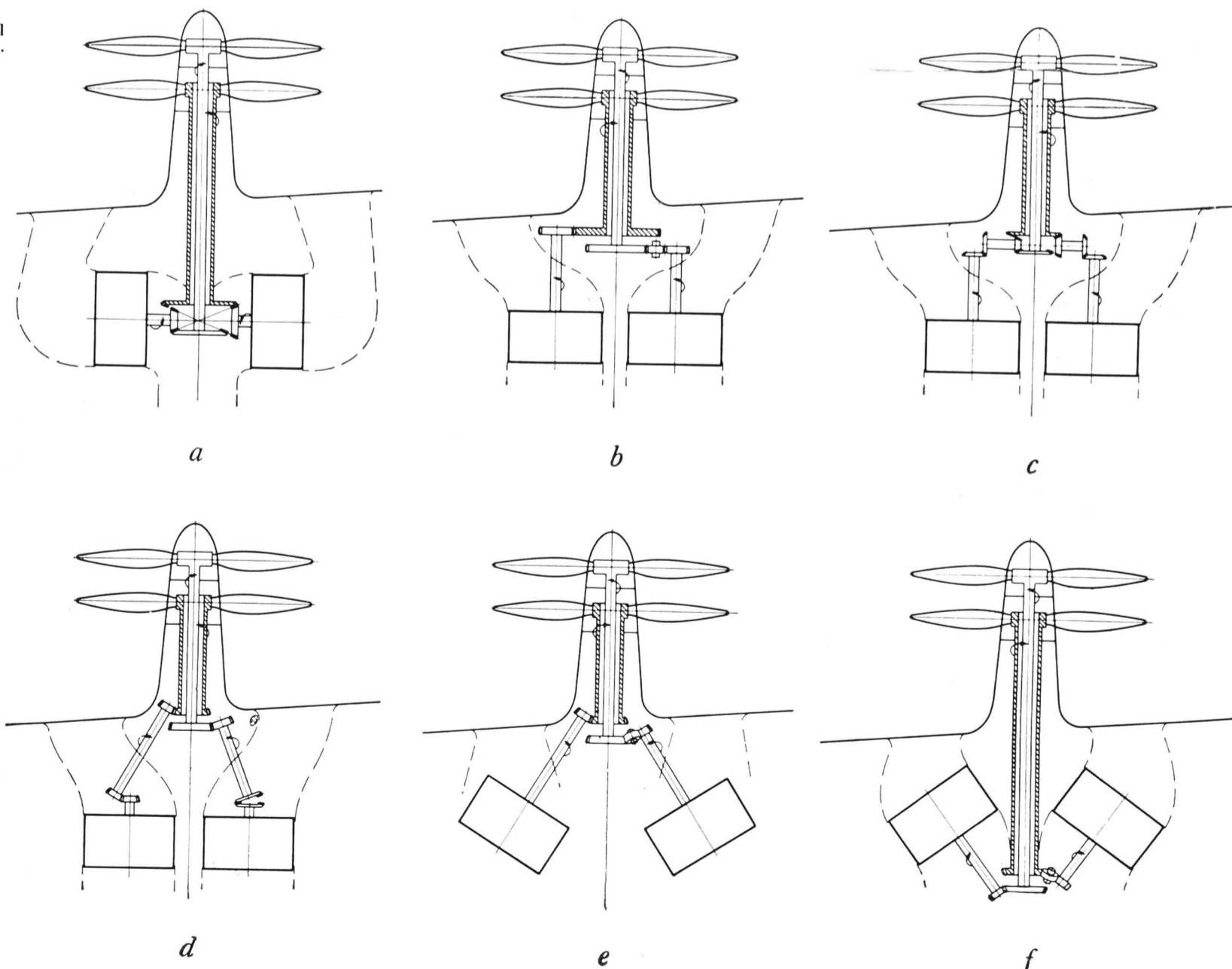
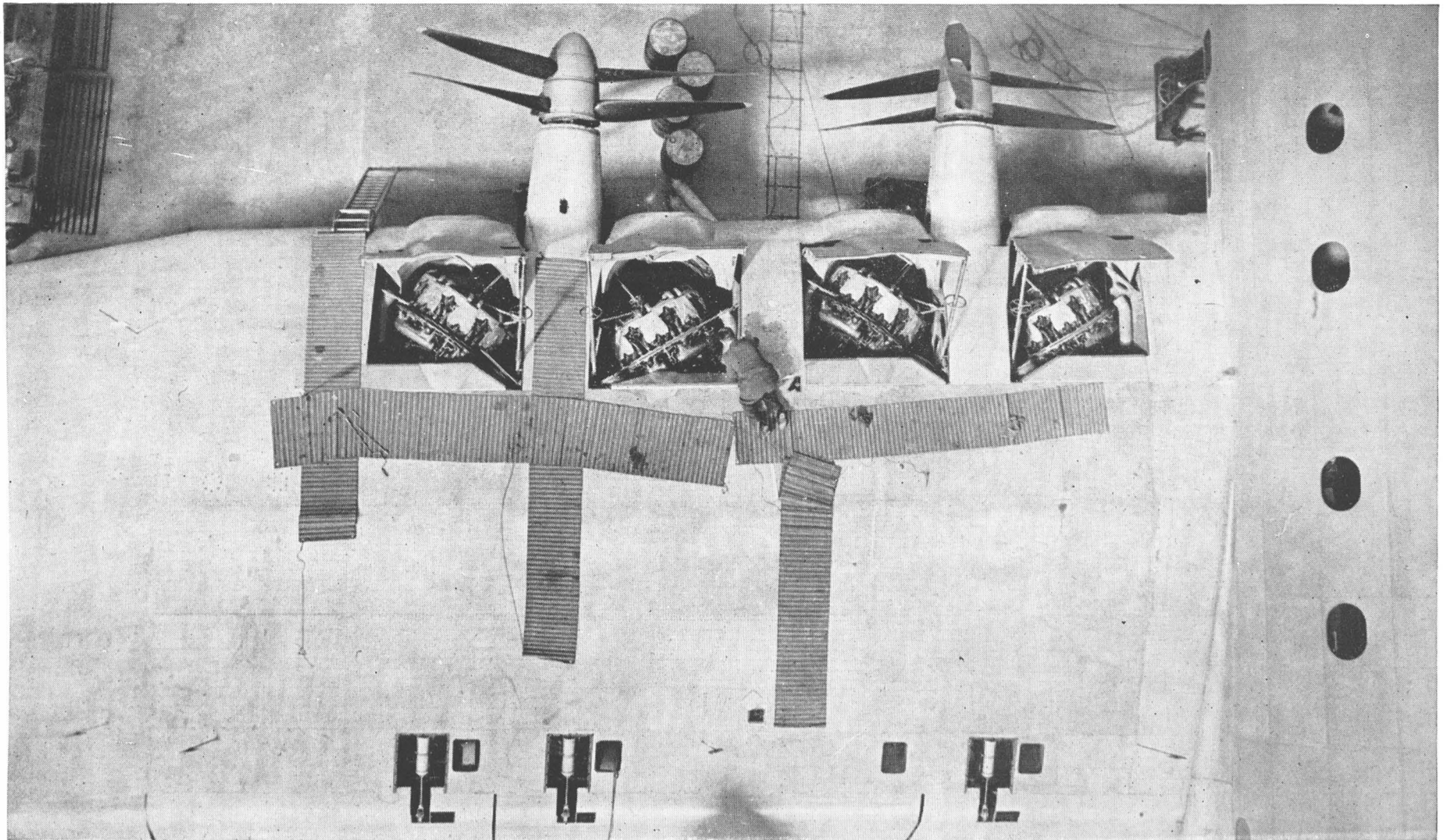


Fig. 1.— Six engine layouts investigated

- a Co-axial engines.
- b Parallel engines, 'V' drive.
- c Parallel engines, spur drive.
- d 'V' drive.
- e Parallel engines, bevel drive.
- f Reversed 'V' drive.

**Fig. 2.—
Bird's-eye view of
engine installed
in the Brabazon**



A further requirement was that the engines and transmission units should be easily accessible for maintenance purposes, and should preferably be capable of installation and removal as separate units.

After very careful consideration of all these factors, it was ultimately decided that the 'V' arrangement of engines as shown in FIG 2 would give the best compromise. An initial design specification was therefore drawn up on this basis, and serious work was begun.

Engines

For this installation, the standard 'Centaurus' 57 (FIG. 3) was taken as a basic type and was adapted by the replacement of the reduction gear and front cover with a new front cover of simplified design (FIG. 4). The engine crankshaft was long enough to carry at its forward end a simple driving-flange. This mark of engine is known as 'Centaurus' 20.

General Layout of Power Plant

FIG. 5 shows the layout of the power plant in the wing. Two 'Centaurus' 20 engines are housed separately in fire-proof cells in the leading edge of the wing. Their centre lines converge forward at an included angle of 64 deg., and the engines are supported on the box-section cantilever structure which separates the two engine cells. This structure, carried by the wing spar, is formed by a pair of nose ribs together with the upper and lower wing skins. Suitable reinforcement is incorporated in the design to provide for all the loads imposed by engine and gearbox weight, propeller thrust and weight, and propeller gyro loads, which last occur only with one engine out of action.

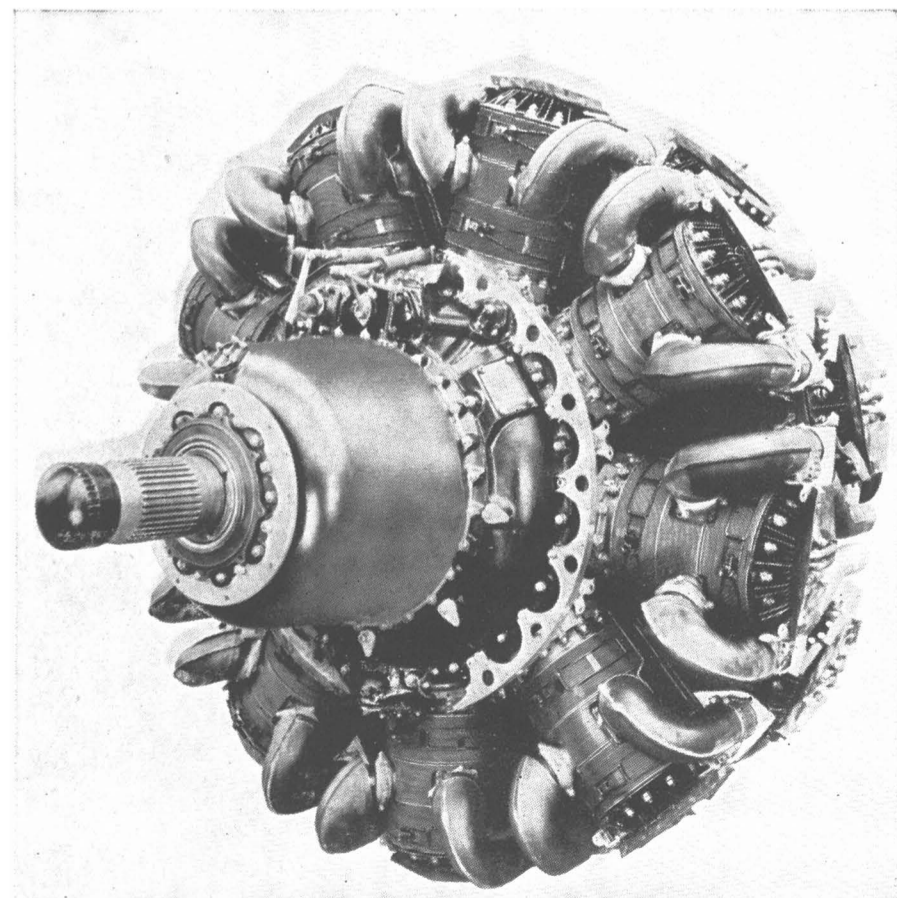
The forward extremity of this cantilever is closed by a diaphragm to which is bolted the propeller 'stalk'. The dual-reduction gearbox is secured within this monocoque structure, and flexibly jointed primary-drive shafts convey the power from the two engines.

The propellers are carried on concentric shafts extending forward from the dual-reduction gear and, to minimize aerodynamic interference, are situated some distance ahead of the leading edge. The forward ends of the shafts are supported in a bearing carried by the closure of the propeller 'stalk'.

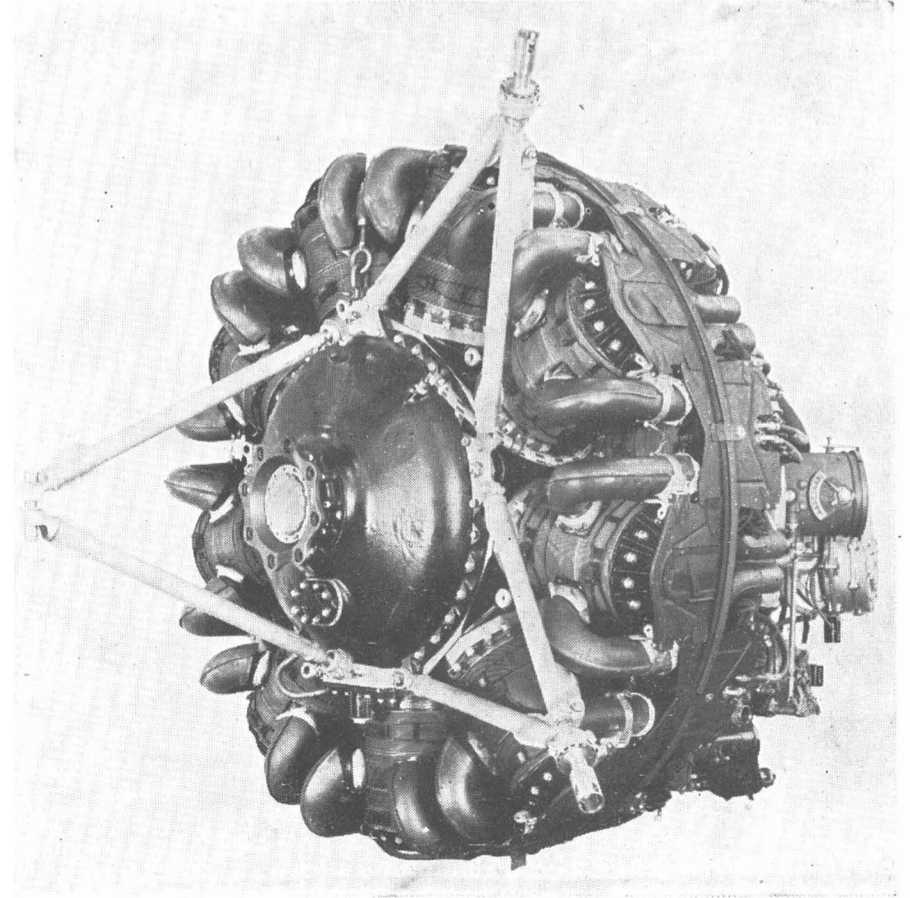
Access to the engines is obtained through large openings in the upper and lower wing skins. These openings are closed by doors hinged at their forward edges just aft of the extreme leading edge of the wing (FIG. 2).

Engine Mounting

The traditional method of mounting a radial engine in an airframe is through the medium of a stiff rectangular section ring secured to the engine crankcase bolts (FIG. 6). A triangulated tubular structure is attached to this ring and terminates in four fixing points at the aircraft structure. The whole arrangement is, in general, symmetrical.



**Fig. 3 (left).—
Centaurus 57
engine**



**Fig. 4 (right).—
Centaurus 20
engine**

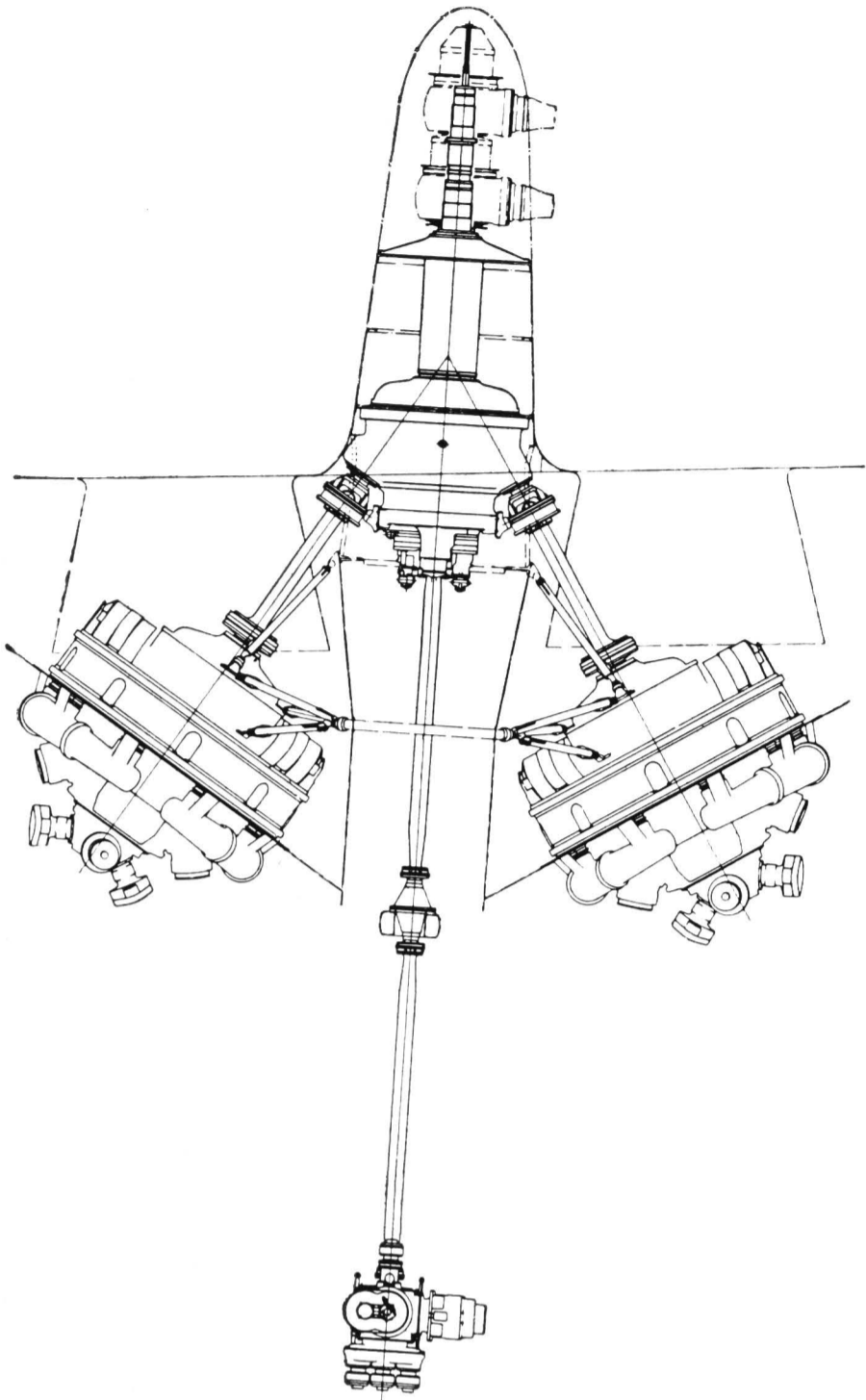
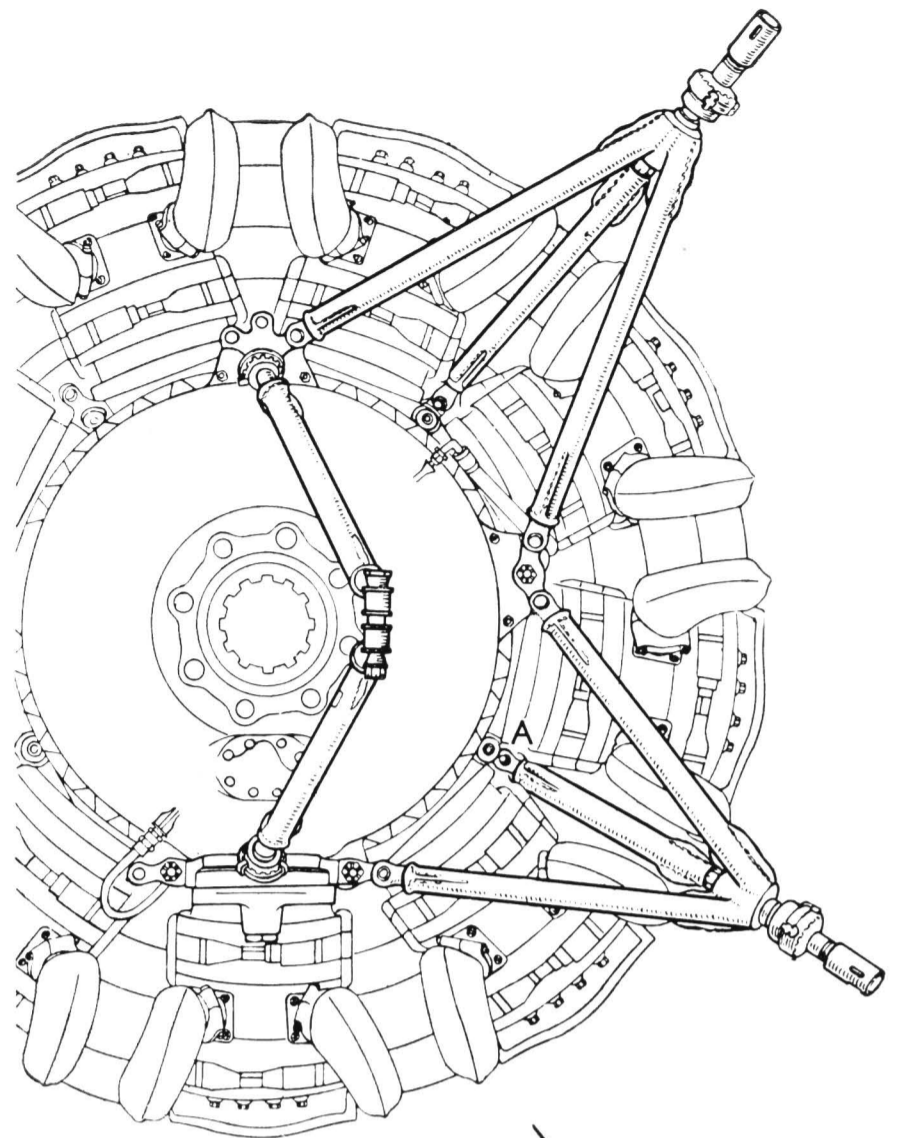


Fig. 5.—Layout of power plant in the wing



DETAIL AT A

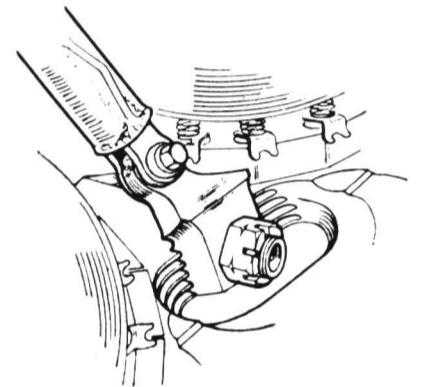


Fig. 7.—Engine mounting, brackets and struts

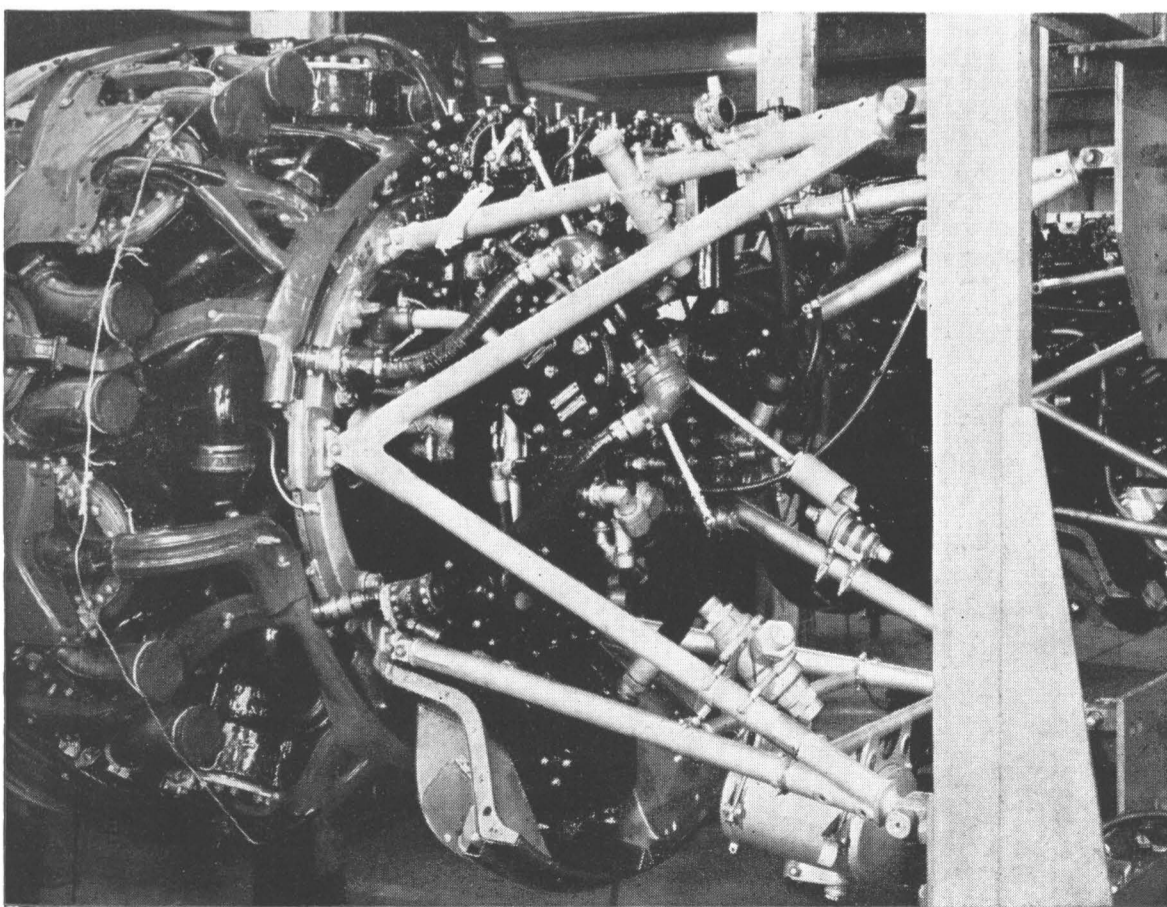


Fig. 6.—Engine mounting, normal design
Hercules 733 in Solent

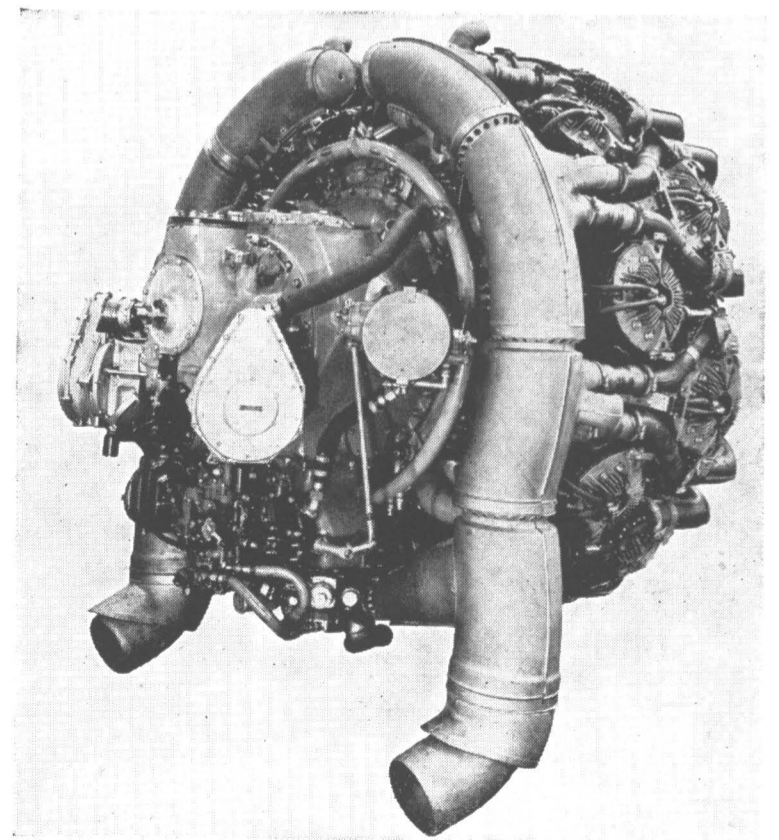


Fig. 8.—Exhaust system

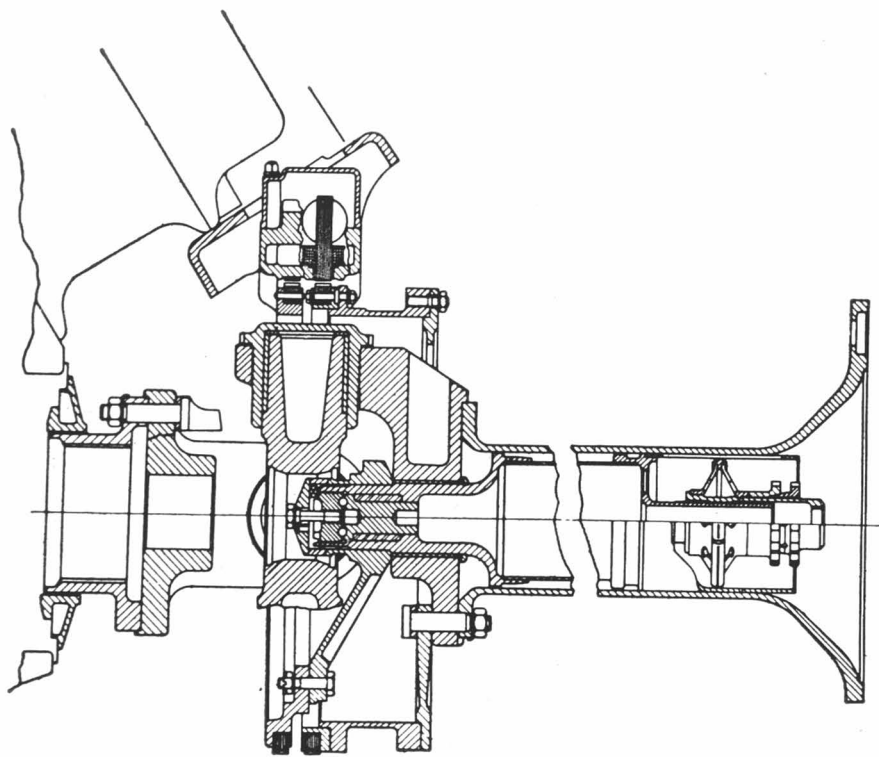


Fig. 9 (left).—Arrangement of primary-drive shaft and torque meter

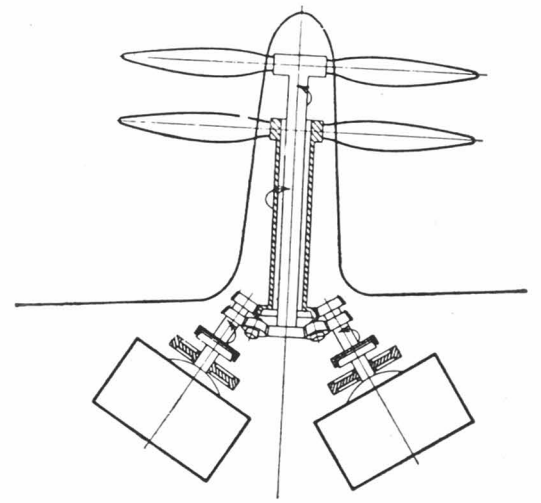


Fig. 10 (right).—True 'coupled engine' arrangement

The departure from established practice embarked upon for this aircraft was necessary to avoid any adverse effect on primary-drive shaft alignment due to wing flexure or propeller stalk 'nodding'. It was decided, therefore, that both engines, together with the dual-reduction gear, should be grouped as closely together as possible, thus forming, with the forward half of the cantilever structure, a compact unit which would be unaffected by wing deflexion. This necessitated 'picking up' each engine at the side rather than at the rear. From many alternative lay-out geometries investigated, the final choice was a structure with the minimum number of redundancies and using a three-point attachment to the aircraft structure. This design (FIG. 7) consists of a pair of tripods attached to the engine crankcase at their feet, and with their apices secured at points near the top and bottom respectively of the cantilever structure. These tripods were designed to provide for all vertical and side loads and engine torque reaction. To accommodate fore-and-aft loads and to stabilize the assembly against pitching moments, two further tubes were provided, connecting top and bottom of the crankcase to a common point forward on the cantilever structure.

To simplify engine removal, quickly detachable couplings were provided at the apices of the two tripods and at the engine ends of the stabilizer tubes. A special form of joint was devised for use at the forward end of the stabilizers, which permitted these tubes to be swung to one side without the necessity of releasing the forward joint bolt.

The weight of engine and accessories supported by this mounting is 3,200 lb., and for this particular application, design for eight times this weight was necessary to cover the accelerations imposed during heavy landings. In addition to flight loads, there were vibration loads set up by the crankshaft and the articulated connecting-rod system, for which provision had to be made.

These are common to all radial reciprocating engines.

The material used in the construction of the engine mounting tubes is a chromium-molybdenum steel to specification DTD 178 (now T.53). The end fittings are of a '40' carbon steel to specification DTD 126, and these are welded to the tubes. The weight of the entire mounting, including bolts, etc., is 60 lb. (compared with about 120 lb. for a representative mounting of normal type). It is interesting to note that, during the course of static loading tests on the first sample of this mounting, permanent set occurred at a load 25 per cent above the design condition, and a load equivalent to an acceleration of approximately 15g was applied before failure took place.

Exhaust System and Cowling

To ensure efficient cooling of the engine, the cylinders are closely jacketed with sheet-metal baffles and a cylindrical cowl completely encircles the cylinder heads. The engine 'cell' is divided by a diaphragm which in turn encircles the cowling. Slip-stream air admitted through the leading-edge opening, therefore, fills the forward portion of the cell under pressure, which causes it to pass between the cylinder and cylinder-head cooling fins. This air finally escapes from the rear compartment through upper and lower outlet flaps in the wing skins. In normal flight the lower outlet only is used.

The exhaust discharge from each cylinder is piped back to a pair of arc-shaped manifolds located behind the cylinders, and having their outlets projecting rearward through holes in the lower engine access door. To limit temperatures in the rear engine bay, and at the same time to reduce the risk of fire, the entire exhaust system is air-jacketed by means of thin stainless-steel shrouding. Air enters under ram pressure from the forward section of the engine cell and is discharged through holes at the end of each section of the shrouding (FIG. 8).

Primary-drive Shaft and Torque Meter

The arrangement of the primary-drive shaft and torque meter is shown in FIG. 9. The power from each engine is transmitted to the dual-reduction gear through the medium of a tubular shaft flexibly jointed at each end. At the rear end, a joint of the 'Layrub' type is used, which consists of a ring of aluminium alloy carrying a number of rubber units with bonded steel centres. The ring is secured to the engine output flange, and the steel centres are bolted to the rear flange of the primary-drive shaft tube. At the forward end a joint of the Hooke's type was adopted. This was specially designed for this application, and uses two yokes machined all over from nickel-chromium steel forgings with a central star piece of 'Hykro' (DTD 306) nitrated all over. The bearing sleeves are made of 'Tufnol', and work in hardened steel bushes screwed directly into the ams of the yokes. The Hooke's type of joint was used at the forward end of the shaft to permit the shaft to be swung to one side after disconnecting the rear end, and so to provide space for engine removal. A torsionally rigid type of joint used at one end of the shaft reduced the possibility of free torsional oscillation of the shaft.

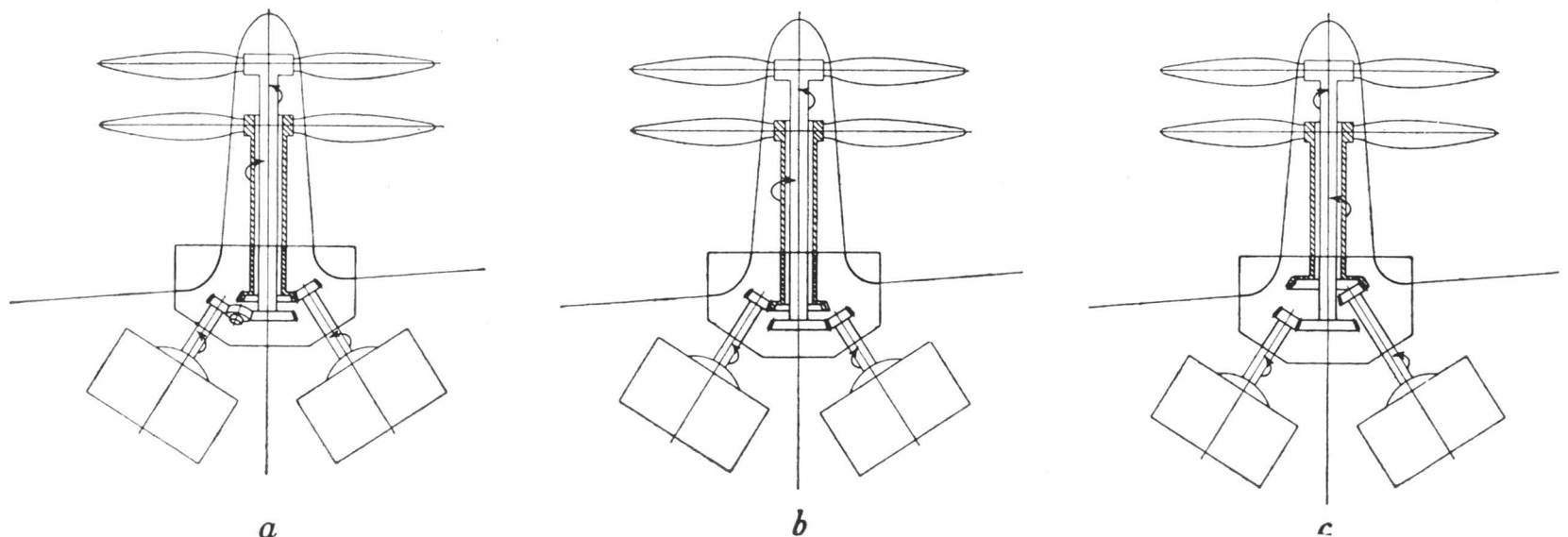
Advantage was also taken of the design of this joint in devising the engine torque meter. This device indicates engine torque as determined by the magnitude of torsional deflexion in the primary-drive shaft tube. Two toothed inductor rings encircle the Hooke's joint and rotate with it; one is secured to the rear yoke but the other is driven by a concentric tube inside the primary-drive shaft. This tube is locked to the bore near to the engine end. Adjacent to each inductor ring is an electro-magnetic pick-up, and when the rings rotate, an alternating current is generated in the windings of each pick-up. Since the inductor rings bear an angular relationship to each other, depending upon torque, the two electrical outputs will bear a corresponding phase relationship to each other. This relationship is determined electrically and is indicated on a suitably calibrated micro-ammeter at the engineers' station.

Dual-reduction Gear

This reduction gear is really two separate reduction-gear trains contained in a common case. Originally, it was proposed to couple the two

Fig. 11.—Dual-reduction gear train (diagrammatic)

- a With idler.
- b With 'handed' engine.
- c With 'reverted' bevel.



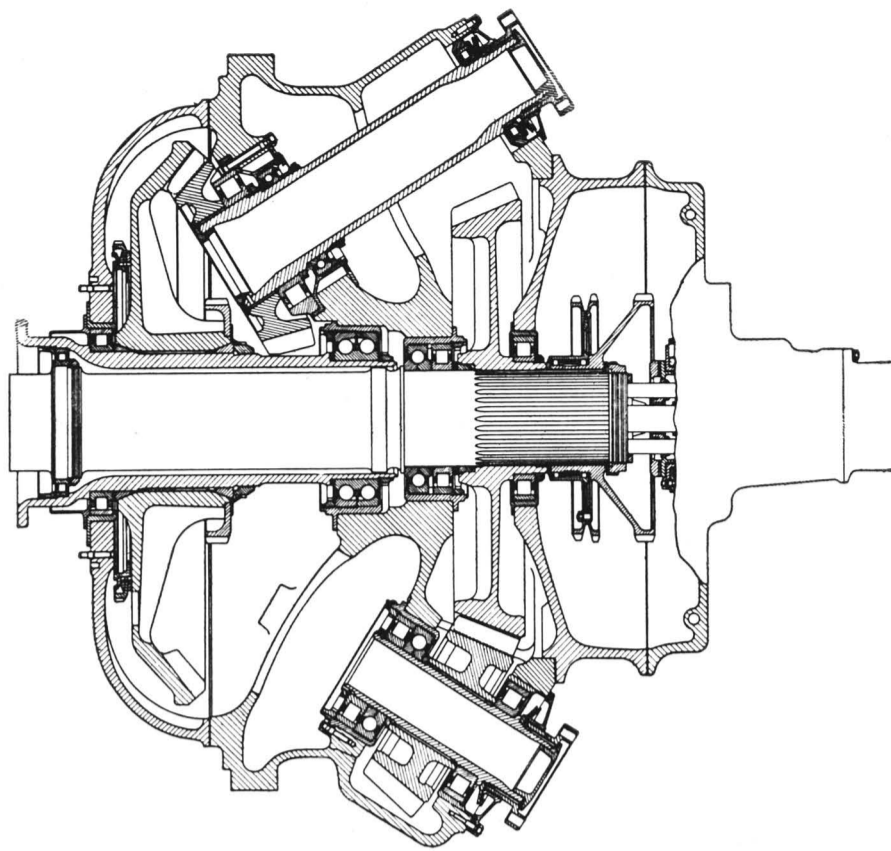


Fig. 12.—Horizontal section of dual-reduction gear

engines together mechanically and to drive a true contra-rotation propeller (FIG. 10). This would have necessitated a clutch in each drive to facilitate starting and to isolate either engine, and the clutch would have had to be of such a design that, when engaged, a fixed known angular relationship would exist between the two engine crankshafts. The need for this is dictated by the torsional vibration characteristics of the engine. Furthermore, aircraft engines do not normally need flywheels, since the propellers they drive have a sufficiently high moment of inertia without them. With the true coupled system it would have been necessary to provide a flywheel on each engine to achieve satisfactory starting and running prior to clutch engagement. It was decided to let each engine drive its own propeller independently, and to have no clutches, no flywheels, and no phasing problem. Ways and means were then sought of achieving the most efficient and lightest form of reduction gear.

Since the main-drive shafts were to be arranged at an angle, the use of bevel gears could not be avoided. From some eight or ten possible lay-outs three probable schemes were evolved:

(1) A straightforward bevel train for both left-hand and right-hand engines, with a bevel idler interposed between the pinion and wheel of the left-hand train (FIG. 11a).

(2) A straightforward pair of bevels for both the left-hand and right-hand drives (FIG. 11b). This system required a virtually new engine on one side with reversed crankshaft rotation. Although this could have been done it would have entailed a large amount of extra work, since a number of new components, including oil pumps, crankshaft, cylinder sleeves, etc., would be required, and the engine would have had to pass numerous tests for approval of basic type.

(3) A simple pair of bevels between the left-hand engine and the inner propeller shaft, and a 'reverted' or internal bevel and pinion between the right-hand engine and the outer airscrew shaft (FIG. 11c).

In finally adopting the reverted bevel scheme the following major features were considered.

Compactness. The complete assembly would be more compact with this system, the casing being of a generally circular form without large excrescences other than those housing the two input shafts. The degree of symmetry thus afforded would not only help the foundry in producing sound castings but would also help to ensure symmetrical thermal distribution.

Weight. The elimination of idlers with their bearings, etc., would result in an appreciable saving in weight, and the compact design would be

conducive to the use of a minimum quantity of metal for a given degree of stiffness.

Efficiency. In the early stages it was considered that there would be an efficiency drop of about 1 per cent for each tooth contact. That is to say, it was assumed that an efficiency of 99 per cent would obtain for a pair of gears, 98 per cent for a three-gear train, and so on. Optimistically, however, calculations were based on a 0.7 per cent drop in efficiency through each half of the proposed reduction gear. With the interposition of an idler it was assumed that a further 0.7 per cent efficiency drop would occur in the one gear train. Although 0.7 per cent does not sound very much, it can be converted into terms of weight, or payload penalty, quite easily, and this would result in a direct increase in fuel consumption. The consumption of 'Centaurus' 20 when cruising at maximum power in 'lean mixture', is 0.436 lb. per b.h.p. hr., and the power at this condition is 1,745 h.p. In a flight time of 12 hours, it will be seen that, to cover the suggested efficiency drop on four engines (since only four engines would require the idler) the amount of extra fuel required at take-off would be $1,745 \times 0.436 \times 4 \times 12 \times 0.007 = 256$ lb., which represents more than one passenger with baggage. This quantity of fuel would, however, require extra tankage which, in turn, would increase the weight.

In the oil system, there would be another increase in weight. The oil is circulated round the gearbox for the purpose of lubrication and cooling; heat removed by the oil is dissipated by means of an oil cooler located in the wing and supplied with air from the forward portion of the engine cell. If the heat rejected from one gear train is doubled, then for a given temperature rise the quantity of oil to be circulated also has to be doubled. Furthermore, the capacity of the oil cooler has to be increased, and this can only be done with an oil cooler of greater weight. It has already been estimated that a payload reduction of 1 lb. would mean a total revenue loss of about £1,000. An efficiency reduction of around 1 per cent would be too expensive to contemplate; therefore there was much to be gained by the use of an internal bevel. The production of an internal bevel was, however, a difficulty. Details of the gears are given in TABLE I.

A survey of all available bevel-tooth generating machinery showed that the maximum degree of 'reversion' which could be produced was of the order of 8 or 9 deg. Thus, it was not possible to generate involute teeth of an internal bevel gear as required, and some deviation from a generated tooth form was necessary, which entailed careful theoretical investigation into possible tooth form variations. The degree of curvature of tooth flank was very small, and could be changed by varia-

tions of pressure angle and degree of tip-and-root correction. Many such variations were considered and, finally, a tooth form was derived which was almost, but not quite, straight or flat. Since this could still have been produced to the required degree of accuracy only by generation, it was decided to consider the effect of using a completely flat flanked tooth. This proved possible, but it involved some modification to the involute form of the tooth of the mating pinion. The nature of the problem had now changed: the manufacture of the internal bevel had become simply a matter of individually machining flat-sided teeth, with a high degree of accuracy; the difficulty now was to produce teeth of conjugate form on the mating pinion. From a study of the 'Gleason' method of bevel-tooth generation it appeared theoretically possible to modify a machine in such a way that the desired tooth form could be generated, and after consultation with gear manufacturers it was decided to proceed with this design.

Main Drives and Casings

The basic lay-out of the main drives is shown in FIG. 12, from which it is seen that ball or roller bearings are provided for all major shafts. These are housed in aluminium-bronze housings which, in turn, are shrunk into the casing. All bevel and spur gears are serrated to their shafts, and clamped endwise by ring nuts. In the early stages of testing, the internal bevel sustained cracking round the hub due to inadequacy of support, and subsequently it was stiffened, and clamped between cones seating on plain parallel parts of the propeller shaft. All nuts securing main gears are tightened to predetermined torques, which are sometimes quite high; for instance, the nut securing the internal bevel is tightened to a torque of 2,500 lb.-ft.

In the design of the main casing, load distribution received careful consideration. Thus, all propulsion thrust-loads, plus bevel thrust-loads and a percentage of radial load, are concentrated around the one central boss of the main casing. This boss is located at the apex of the deeply corrugated conical diaphragm structure forming the main body of the casing. The outer periphery of this structure is blended into the strengthened forward part of the casing which forms the means of attachment to the airframe. This design ensures that the propeller thrust is transmitted through the minimum amount of cast structure, and the stresses imposed upon that structure are mainly compressive, thus reducing the chance of fatigue failure (FIG. 13).

The mutual loading imposed by the right-hand bevel pinion and the internal bevel produces stresses which again are compressive and, since the bearings carrying these loads are near together, the deflexions are correspondingly small.

The configuration of the assembly of the rear

TABLE I. LEADING PARTICULARS OF MAIN BEVELS

Drive from engine ...	Left-hand		Right-hand	
	Ratio ...	0.4/1		0.4/1
Bevel ...	Wheel	Pinion	Wheel	Pinion
Number of teeth ...	50	20	70	28
Pitch-circle diameter, inches ...	21.739	8.696	25.0	10.0
Angle (degrees, minutes, seconds) ...	23 0 22	8 59 38	49 47 7	17 47 7
Diametral pitch ...	2.3		2.8	
Pressure angle, degrees	20		20	
Tooth speed, ft. per sec. at maximum cruise	91.1		104.7	
Tooth stress, lb. per in. of tooth width at maximum cruise ...	4,012		4,720	
Material ...	Case hardening, nickel-chromium steel (similar to S.82)			
Treatment ...	Case hardened on teeth to 0.060 inch depth			

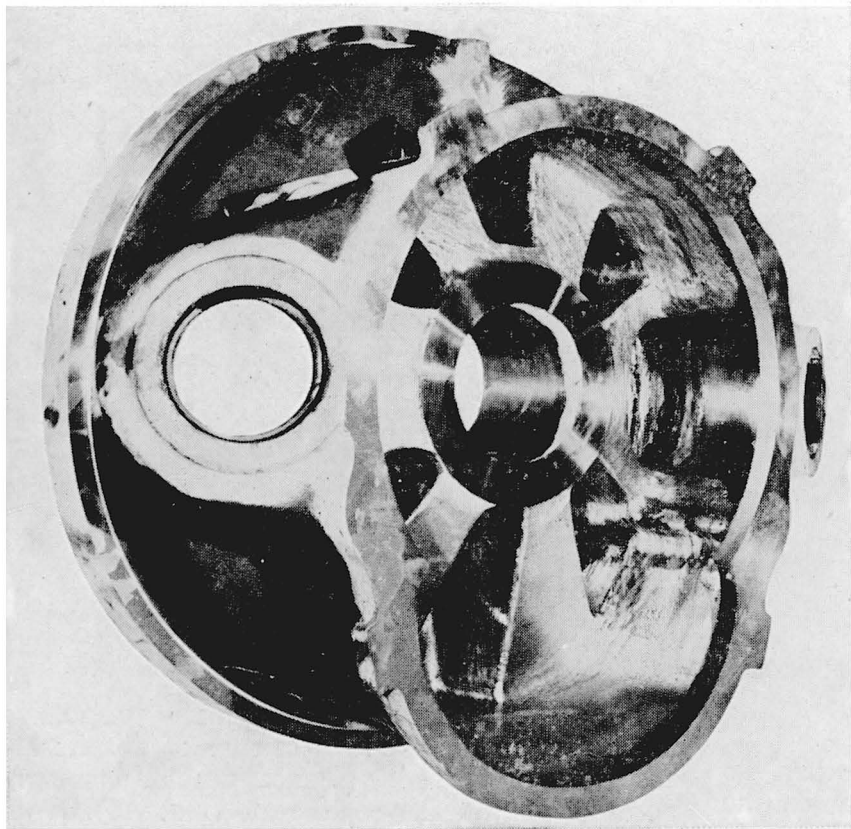


Fig. 13.—Casting for main casing of dual-reduction gear
Overall size, $36\frac{1}{2} \times 19\frac{1}{2} \times 18$ in.; weight of casting, 242 lb.; weight of finished component, 215 lb.

pair of bevels is not quite so favourable, but, on the other hand, the bevel thrust is lower and it was possible to straddle-mount the pinion, thus reducing load concentration.

Since the distribution of major stresses did not seem too complex, it was decided, after consultation with a foundry specialist, that the main casing members should be designed as magnesium castings (DTD 136). This decision has proved a wise one as, notwithstanding most stringent inspection, including 100 per cent radiography, not one of these castings has been rejected from any cause whatever by the Bristol Aeroplane Company.

In aircraft engine design, weights are of necessity kept low, which means that stresses and therefore deflexions are maintained at the highest possible level consistent with safety. With the dual-reduction gear it was important to ensure that gear deflexions under load were not excessive, otherwise poor tooth meshing would result. The magnitude of deflexions were checked by a series of tests. For these tests the main gear trains were assembled into a casing, and both drives were rotated simultaneously at one revolution per minute while increments of torque up to 100 per cent were applied. Gear deflexions were measured

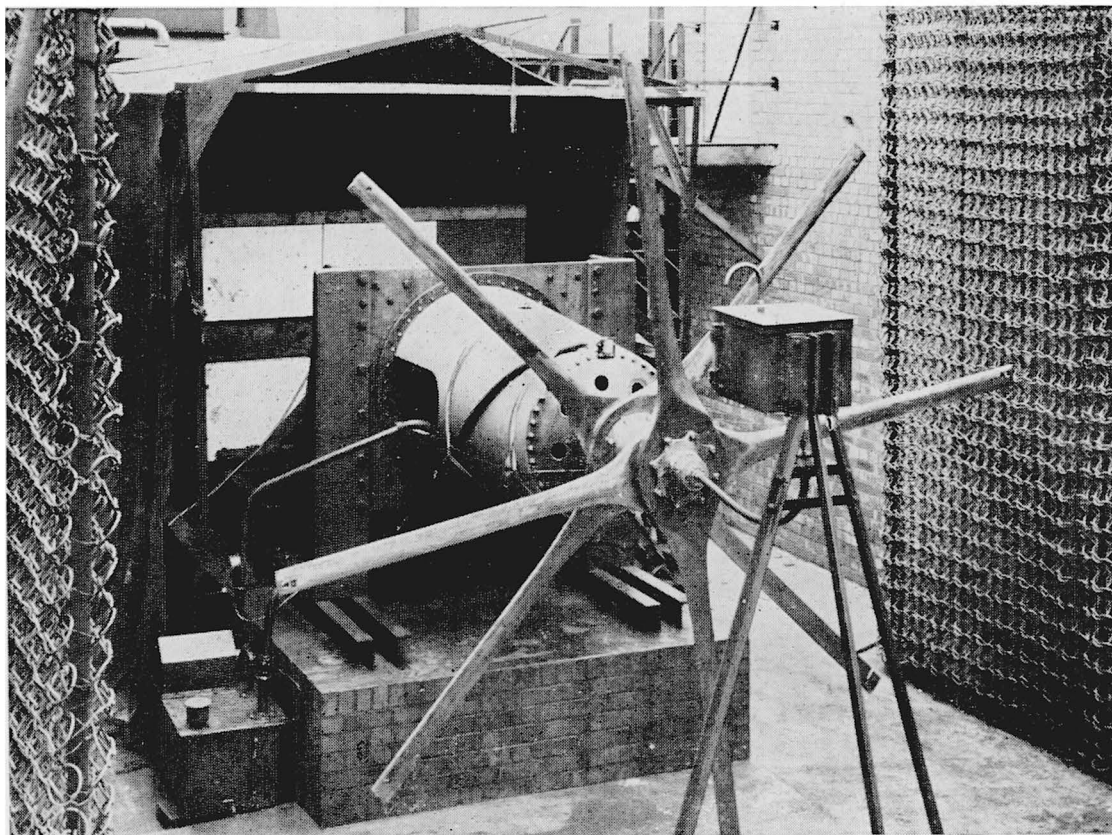


Fig. 14.—'Whirling rig'

by means of many dial indicators contacting through suitable apertures in the casing. The same set-up was used to check bevel-tooth marking under load, during the process of perfecting the gear tooth-cutting technique.

After running the first reduction gear under full-speed maximum-torque conditions, the gear tooth marking surprisingly showed the same pattern as when loaded to only 50 per cent of maximum torque at the near-zero speed condition used on the rig. This might be due to inertia effects causing the point of maximum wheel deflexion to occur just beyond the point of contact. A similar effect can be seen in a polishing shop: when a job is held against the rotating mop, the linen layers separate to a maximum extent some distance beyond the point of contact with the job.

Propeller Shafts

The position of the supports, and the distribution of the masses carried, created a problem in obtaining a satisfactorily high whirling speed of the propeller-shaft system. This problem was complicated by the fact that the supports were themselves flexible.

Two schemes were ultimately evolved. The first, with a whirling speed well above the running range, specified an inner propeller shaft of 6 in. diameter, but required the rear propeller hub to be much larger than the front, with a consequent

weight penalty. The second, with a whirling speed somewhat lower, used a shaft of 4.5 in. diameter, but permitted the rear hub to be the same overall size as the front. Furthermore, the shaft bore could be straight and parallel, thus easing manufacture. This scheme was adopted, with the knowledge that a reversion to the heavier scheme could be made later if the need arose.

To prove the calculations, a special rig, known as the 'whirling rig' was built (FIG. 14). In this, the propeller shafts were carried in, and driven by, a special gearbox supported in a flight-type of propeller 'stalk'. The complete unit was fixed to a stiff stand; dummy propellers were secured to the shafts, and the rig was driven by a 500-h.p. variable-speed motor. To simulate flight conditions as closely as possible, the dummy propellers were of the same weight and moment of inertia as the flight propellers, and the weight and position of the centre of gravity of the gearbox were also similar to those of the flight reduction gear.

The results of these tests were interpreted with reference to the actual wing flexibles. Subsequent checks on the Phase 2 test stand (described later) confirmed the general conclusions reached, and showed that the amplitude of vibration was within an acceptable limit from the point of view of structure stresses.

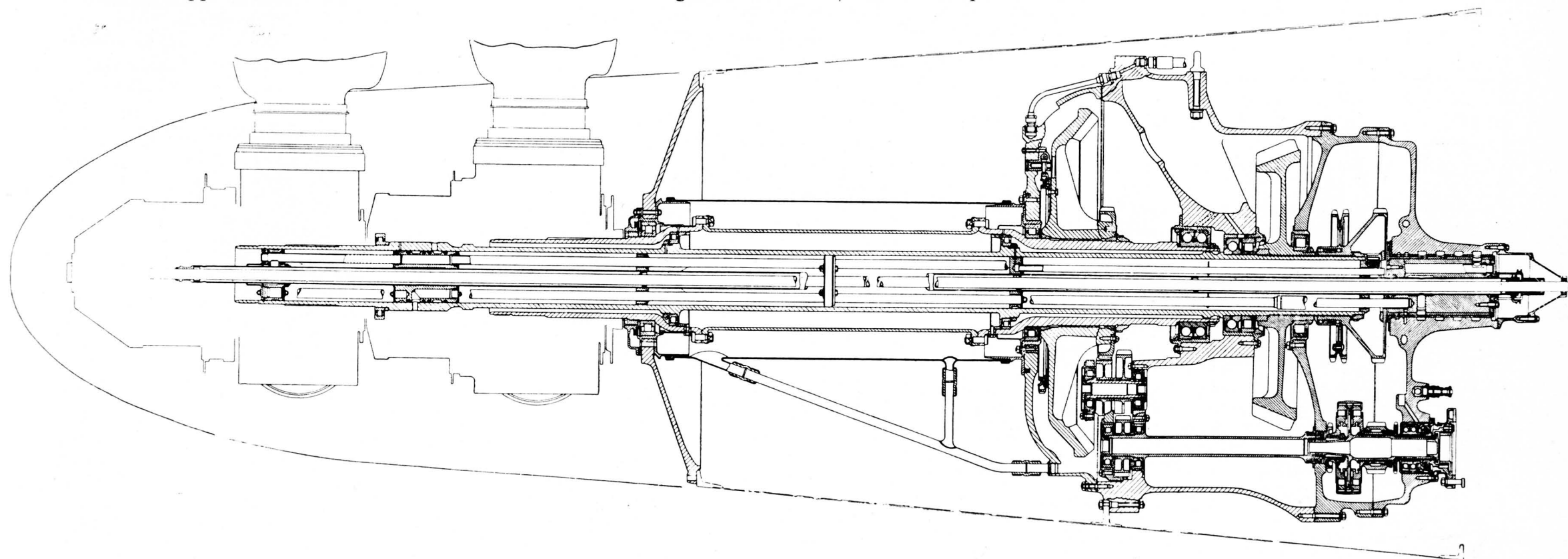


Fig. 15.—Vertical section of dual-reduction gear

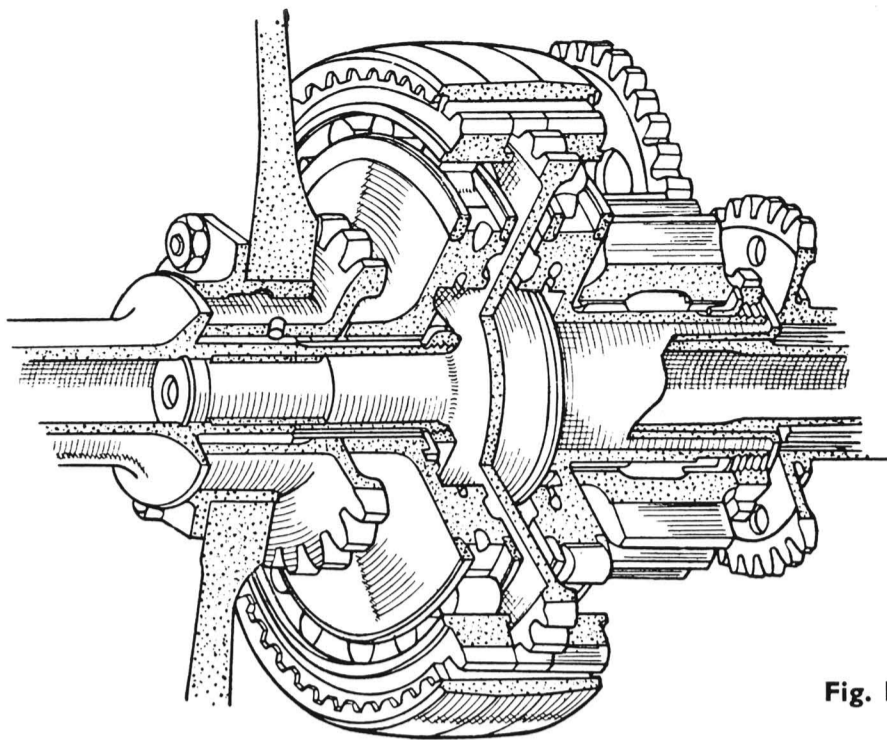


Fig. 16.—Dual freewheel assembly

Auxiliary Drives

A maximum of 275 h.p. is available to drive the accessories necessary for aircraft services. These services include cabin air-conditioning, electric power for engine starting, propeller de-icing, heating, lighting, radio, and hydraulic power for flying control and undercarriage operation, etc.

The power to drive the accessories for these services is obtained from the main engines by tapping the two propeller shafts. Gears, secured to each, mesh with two trains situated towards the front and rear respectively of the reduction gear assembly. Each train ultimately drives through a freewheel thus permitting either engine to slow down or stop without interrupting the drive (FIG. 15).

It was anticipated, during the design stages, that the freewheels would have an arduous time because of the torsional vibration characteristics of the drive system, and the possible frequent

transfer of load from one drive to the other. To alleviate this condition, the ratios between the drives from the two engines were made different; that from the outer propeller shaft is 1.316/1, and that from the inner is 1.28/1. With engines synchronized at 2,400 r.p.m. the right-hand engine provides the entire drive through the forward freewheel, and the other freewheel slips at about 88 relative r.p.m. Thus, the rear propeller operates at a little less power than the slightly more efficient forward one.

FIG. 16 shows the details of the dual freewheel assembly. This is of the jamming roller type, using eighteen rollers in each section. Individually spring-loaded plungers are used to ensure that each roller is maintained in a condition immediately to receive a share of the torque when applied. The outer rings are separate floating members to permit automatic centring under all conditions of load and of shaft deflexion. In addition, this configuration avoids the possibility of roller-end loading due to non-symmetrical expansion under the wedging effect of the rollers.

On test, early trouble was experienced with the freewheels. This took the form of the rollers and outer rings scuffing and discolouring and, sometimes, of rollers running over the cam tips. It was found, however, that no trouble occurred when either slipping 100 per cent or when transmitting positive torque. Investigation indicated that at certain conditions of speed and slip, considerable heat was generated (FIG. 17), owing to the combined effect of centrifugal loading between rollers and outer ring, and rubbing velocity. The trouble was remedied by using lighter rollers made of tungsten steel, 'granodizing' the outer ring, and increasing the cooling-oil supply.

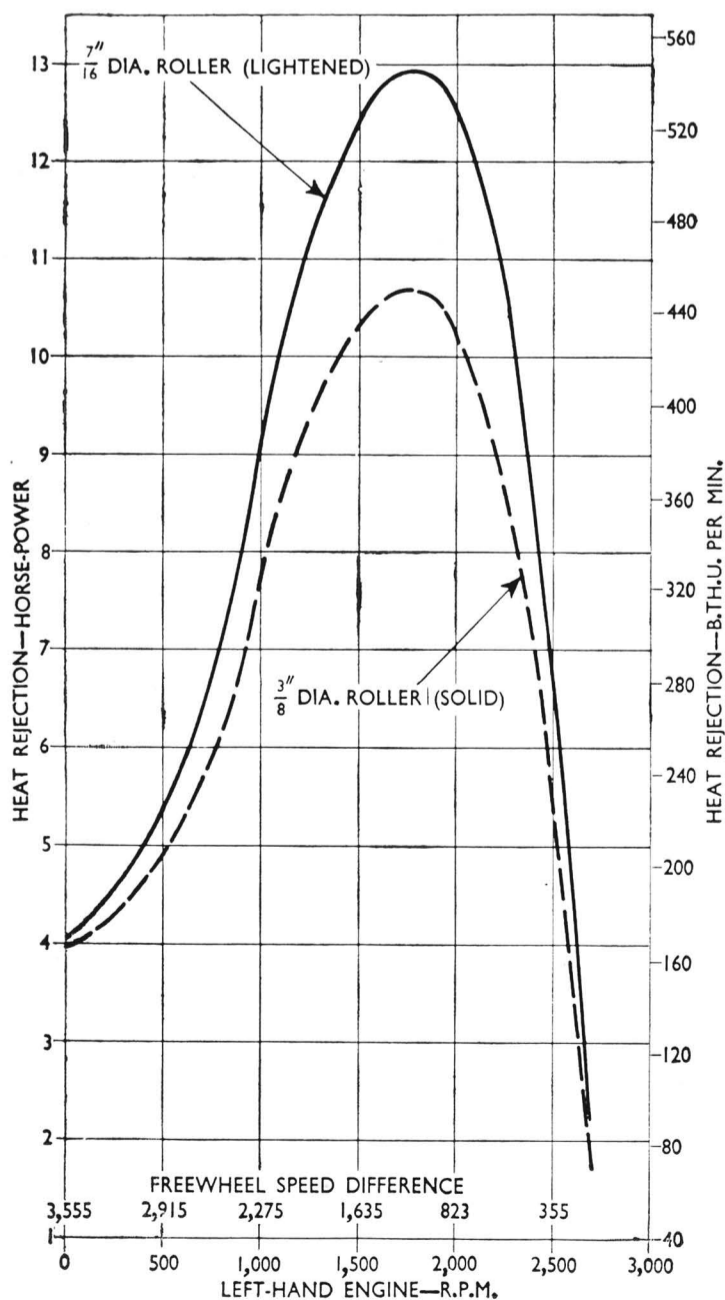


Fig. 17 (left).—Frictional horse-power developed in rear freewheel
Right-hand engine speed 2,700 r.p.m. and constant

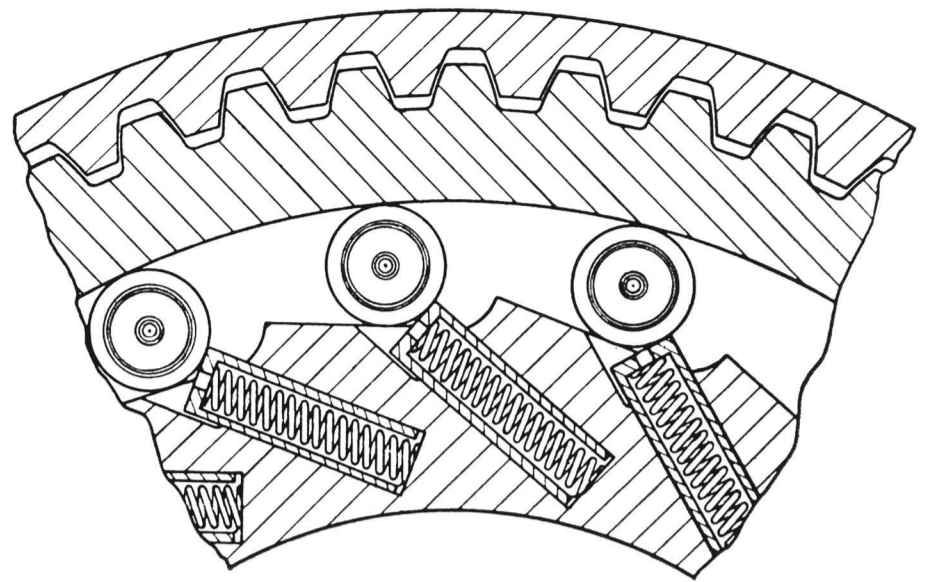


Fig. 18 (right).—Accessory-drive shear link

To prevent damage to the main propulsive machinery in the event of seizure of an aircraft accessory or gearbox, a 'shear link' was incorporated in the drive take-off (FIG. 18). This comprises primary and secondary flanges, held together by a coarse-threaded sleeve of large diameter. The torque is transmitted from the primary to the secondary flange through three dowels of 0.212 in. diameter. Should torque momentarily build up to 130 per cent in excess of the maximum permissible steady figure, the pins shear. The threaded sleeve then unscrews, and the pre-tension in the Layrub couplings causes the primary and secondary flanges to part, thus permitting running to continue without danger of the shear faces rubbing and seizing.

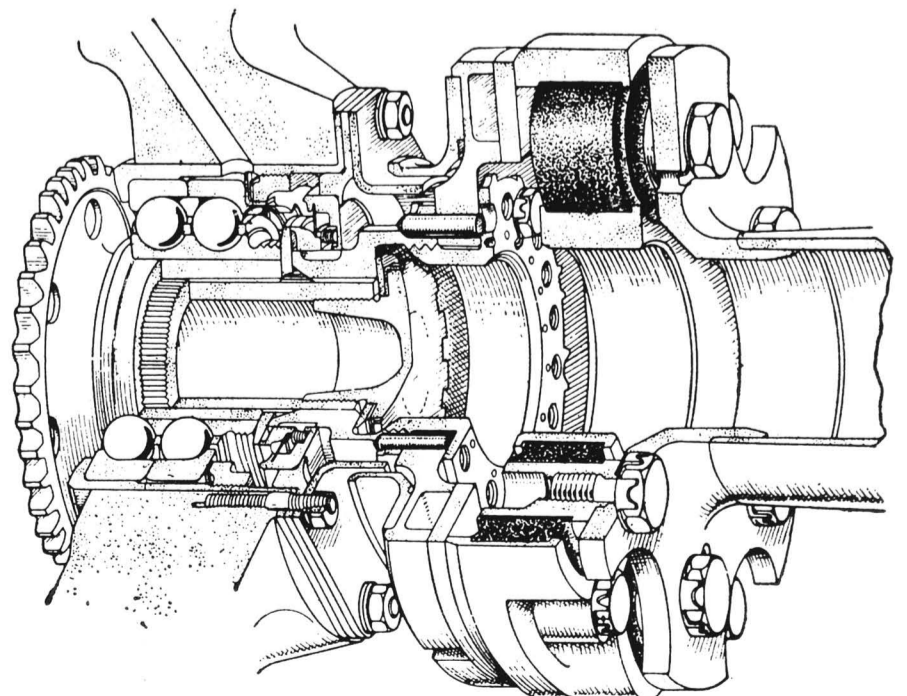
The final drive is coupled, by means of flexibly jointed Cardan shafts, to the aircraft accessory gearbox (FIG. 19). Round this the electric alternator, hydraulic pumps, and cabin blower are grouped. This gearbox lies some 12 ft. aft of the reduction gear, in the wing space, where it is readily accessible even during flight.

Reduction Gear Ancillaries

Grouped on the rear face of the rear cover are the propeller ancillaries, oil pumps, etc. (FIG. 20). The separate gear type of pressure and scavenge pumps are located respectively to the right and left of the accessory power take-off shaft. This shaft provides the drive by means of a spur gear, thus ensuring a continuous oil supply with either engine static.

Oil from the pressure pump, which has a cruising capacity of 300 gal. per hr. is passed first through a 'Purolator' filter, then through drilled passages to the following three services:

- (a) Bearings requiring pressure or independent feed.



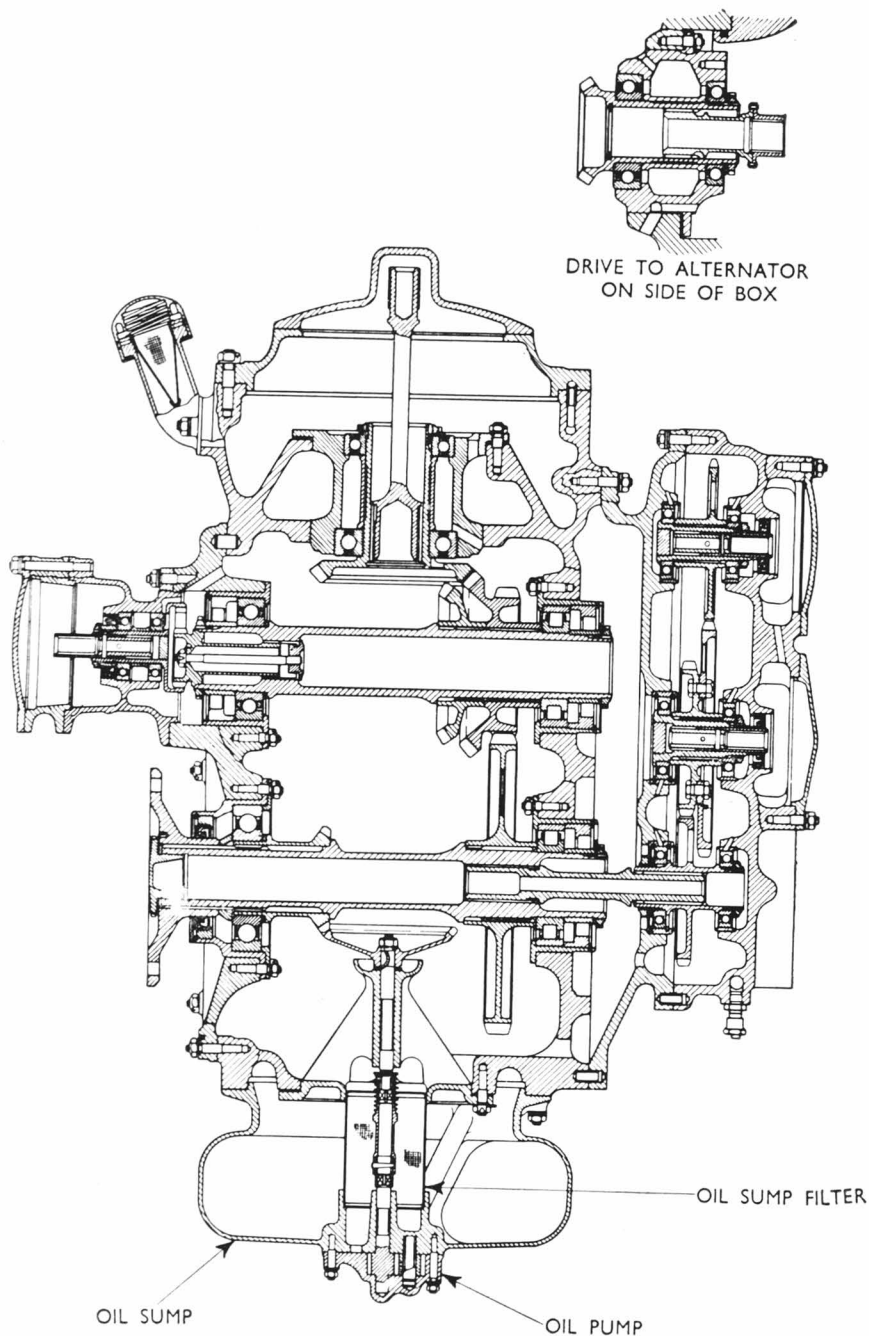


Fig. 19 (left).—Vertical section of accessory gearbox

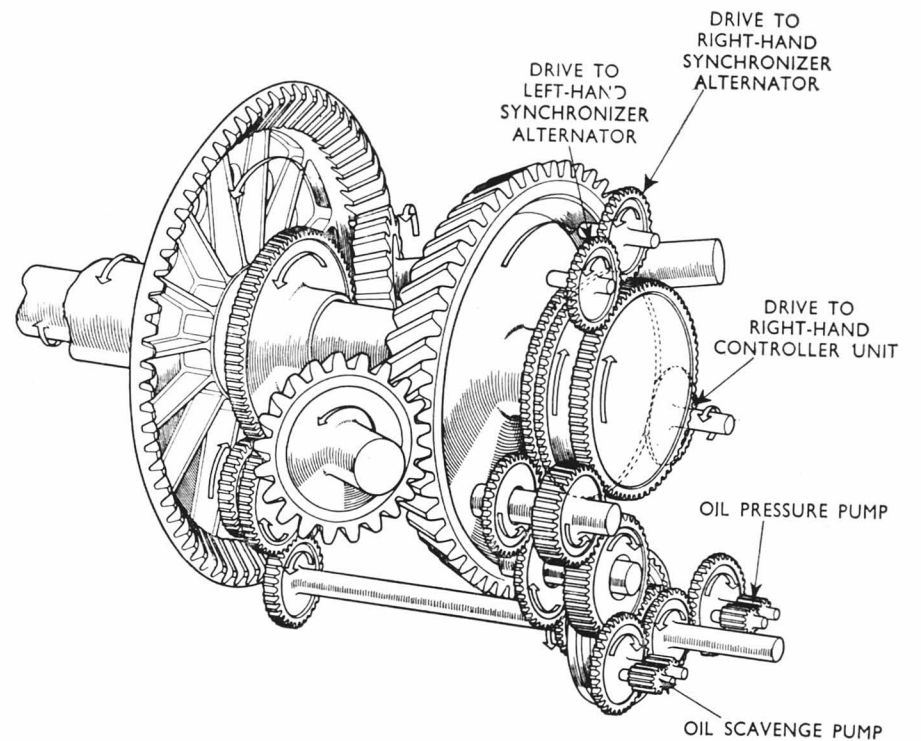


Fig. 20 (right).—Diagram of gear trains

- (b) Gear tooth cooling jets.
(c) The propeller hydraulic system.

For the lubrication of both pairs of main gears, splash is relied upon, but considerable care was taken to ensure adequate cooling of the teeth. To this end, clusters of jets are provided, located as close as possible in the 'V' between the gears on the *disengaging* side. The clearance between the jet tips and the tops of the teeth is of the order of 1/16 in., and the jets are arranged at angles such that each oil stream traverses the whole tooth depth in passing. This design aimed at removing the 'heat charge' from each tooth surface before it had time to 'soak' into the main body of the gear or pinion.

Oil draining away from various parts of the gearbox collects at the bottom, whence it is removed by means of the scavenge pump through a strainer and is returned, through the oil cooler, to the tank.

The supply of lubricant to the plain bearings carrying the accessory-drive shafts in the auxiliary-drive case walls and to certain propeller shaft bearings is metered by means of an intermittent feed. This is provided by ports in the main oil pump gear spindle which feed through successive drillings in the pump body.

No relief valve is employed, but a back-pressure valve is inserted in the circuit to ensure a minimum pressure to the propeller system of 40 lb. per sq. in. This valve is located to the left of the gearbox rear cover (FIG. 21).

The propeller control gear comprises a controller unit, a synchronizing alternator, and a synchronizing corrector motor for each propeller.

With the exception of the corrector motors, these units are driven by two gear trains associated respectively with the left- and right-hand engine (FIG. 20). The controllers rotate at 0.94 engine revolutions, and the synchronizing alternators rotate at exactly engine speed.

Propellers

The three-bladed propellers of 16 ft. diameter are of 'Rotol' design and manufacture, and were produced specially for this installation. The design was carried out in close collaboration with the Bristol Aeroplane Company, since only by so doing was maximum overall efficiency, together with minimum weight, likely to be realized. In general, the propeller blade angle or pitch is changed by hydraulic means, oil being admitted

to the front and rear portions of the cylinder built on to the propeller hub (FIG. 22). The oil pressure is supplied and directed by the controller unit, one being provided for each propeller and driven as previously described. The oil flow and return paths associated with each propeller comprise drilled passages in the rear cover, the rotating oil feed assembly located in the large boss in the centre of the rear cover, a stack of tubes inside the inner propeller shaft, and the oil distributor at the forward end of that shaft.

The functions of the controller units are quite normal, but in this installation the propellers are capable of operating in reverse or negative pitch for the purpose of braking the aircraft and thus reducing the length of landing run.

Safeguards are provided in the system to prevent the propeller blades passing into zero pitch with the throttles open (FIG. 23).

Development Testing Programme

A comprehensive programme of proposals for development testing, drawn up at the time when the general design requirements were settled, was used as the basis for the design and installation of the requisite test plant, and was adhered to fairly closely throughout the entire development period.

Since the engines were of basically well-proven types, only the normal endurance and final tests

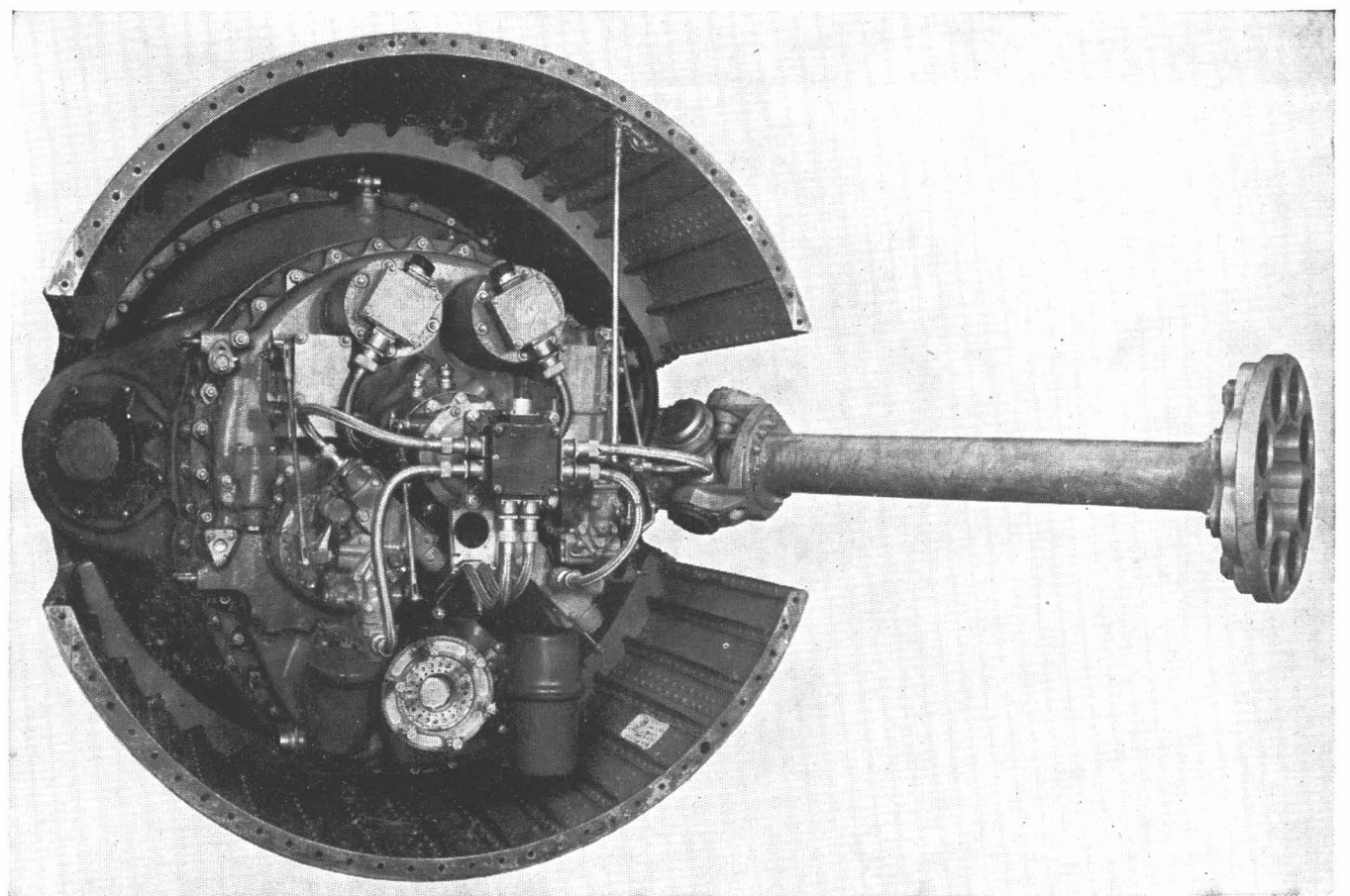


Fig. 21.—Dual-reduction gear mounted in propeller stalk with ancillaries on rear cover

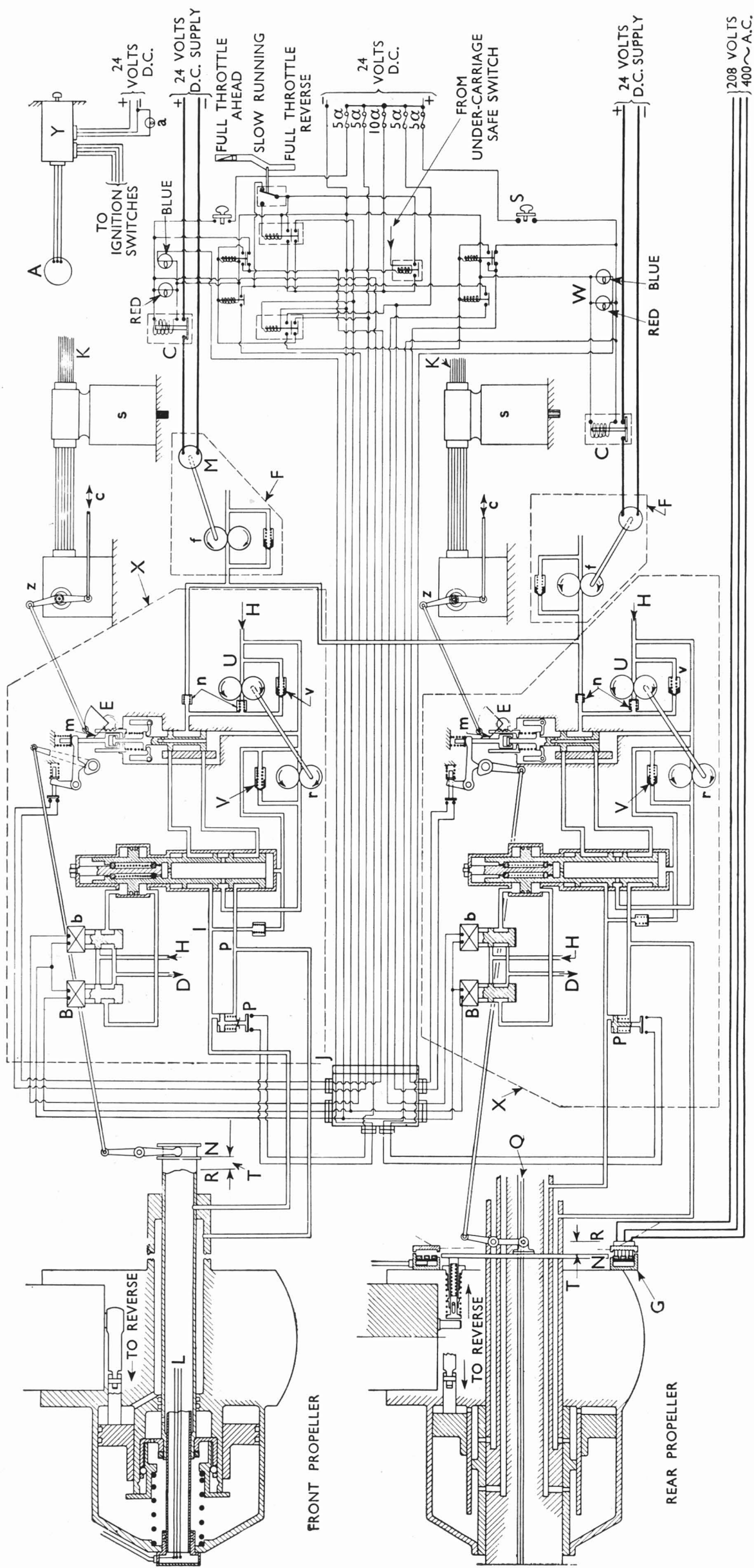


Fig. 23.—Propeller operating system

- A** Alternator.
a Auxiliary lamp.
B Braking solenoid.
b Unbraking solenoid.
C Contractor.
D Control movement, 3-18 in., maximum load 66 lb.
E Drain.
F Feather.
F Feathering pump unit.
G Motor.
H Maximum r.p.m.
I Junction box.
J Connections to synchronizer control panel.
K Leads from de-icing slip rings, front.
L Motor.
M Maximum r.p.m.
N Normal.
P Non-return valve.
P Differential-pressure-operated switch, closes at 400 lb.
Q Decrease pitch.
R Leads from de-icing slip rings, rear.
R Reverse.
S Reverse pump.
S Feathering switch.
T Synchronizer corrector motor.
T Synchronizer corrector motor.
U Synchronizer corrector motor.
V Synchronizer corrector motor.
V Synchronizer corrector motor.
W Synchronizer corrector motor.
W Synchronizer corrector motor.
X Synchronizer corrector motor.
X Synchronizer corrector motor.
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were necessary. These were carried out on a normal test bench, using a water brake to absorb the power.

As regards power-plant testing, it was estimated that some 1,000 hours total running time would be necessary to prove the transmission and other new features. It was expedient to divide this testing into two stages or phases: (1) an exhaustive mechanical test of the reduction gear and transmission system, and (2) testing of the complete power plant installation in a form simulating as nearly as possible the flight installation.

Phase 1 Test Stand (FIG. 24). The simplest way to drive and load the transmission system was to use two 'Centaurus' 20 engines and a pair of propellers. A rigid stand was constructed, to each side of which an engine was attached. The stand carried a steel plate at the front, and the dual-reduction gear, fixed in a robust two-piece steel 'stalk', was secured to it. A small water brake was installed for the purpose of loading the accessory drive.

To ensure adequate engine cooling, suction fans were arranged behind the engines, but these were found later to be unnecessary. All controls, instruments, etc., were taken to a control cabin erected to one side of the test stand.

Running commenced in April 1946. After a few preliminary runs, necessary to ensure the proper functioning of all test-plant services, endurance runs of 2 and 10 hours respectively were made, with stripping and inspection of the dual-reduction gear after each. The results were so promising that the next test was run to approximately official 'type test' conditions, and lasted 114 hours. Inspection after strip revealed an extremely gratifying condition of practically all components. Tooth marking was excellent and all bearings were perfect. The only adverse features were the previously mentioned cracks in the internal bevel boss and the condition of the freewheel rollers and tacks.

During these and subsequent tests careful measurements of heat rejection were made, with the object of determining the gearbox efficiency. An average figure was 23.5 h.p. at steady take-off condition. Since casing temperatures were low, and the casing was protected from the slip-stream an allowance of 25 per cent was thought to be adequate for direct radiation and convection losses. On this basis the mechanical efficiency of the gears was found to be 99.4 per cent.

Up to the time of writing, some 715 hours of development running have been completed on this test stand. This same rig has also been used for passing off all flight reduction gears, etc.

Phase 2 Test Stand (FIG. 25). To closely simulate aircraft conditions, the second phase of the development programme was carried out with the power unit installed in a specially built section of the aeroplane wing. This was fixed on steel supports some 10 ft. above ground level. Provision was made to introduce additional flexibility in the supporting structure, should this be required later during the vibration investigation.

All services, including fuel and oil systems (except fuel tanks), engine-driven aircraft accessories, etc., were installed. The instrumentation was fairly comprehensive, to provide as complete a picture as possible of air, oil, and fuel temperatures, pressures, and flows, etc., as well as of cylinder-head temperatures. Strain-gauges were fixed to engine mounting members, and vibrographs were installed at critical points.

The first series of tests were begun in November 1946 and consisted of a complete vibration exploration. The results confirmed expectations following the 'whirling rig' tests.

This investigation was followed by endurance runs, during which it was found necessary to strengthen the propeller 'stalk' at the cut-away portion round the Hooke's joints in order to avoid fatigue cracking. Certain details of the rib cantilever extension were also found to require strengthening, particularly the ties between main engine mountings.

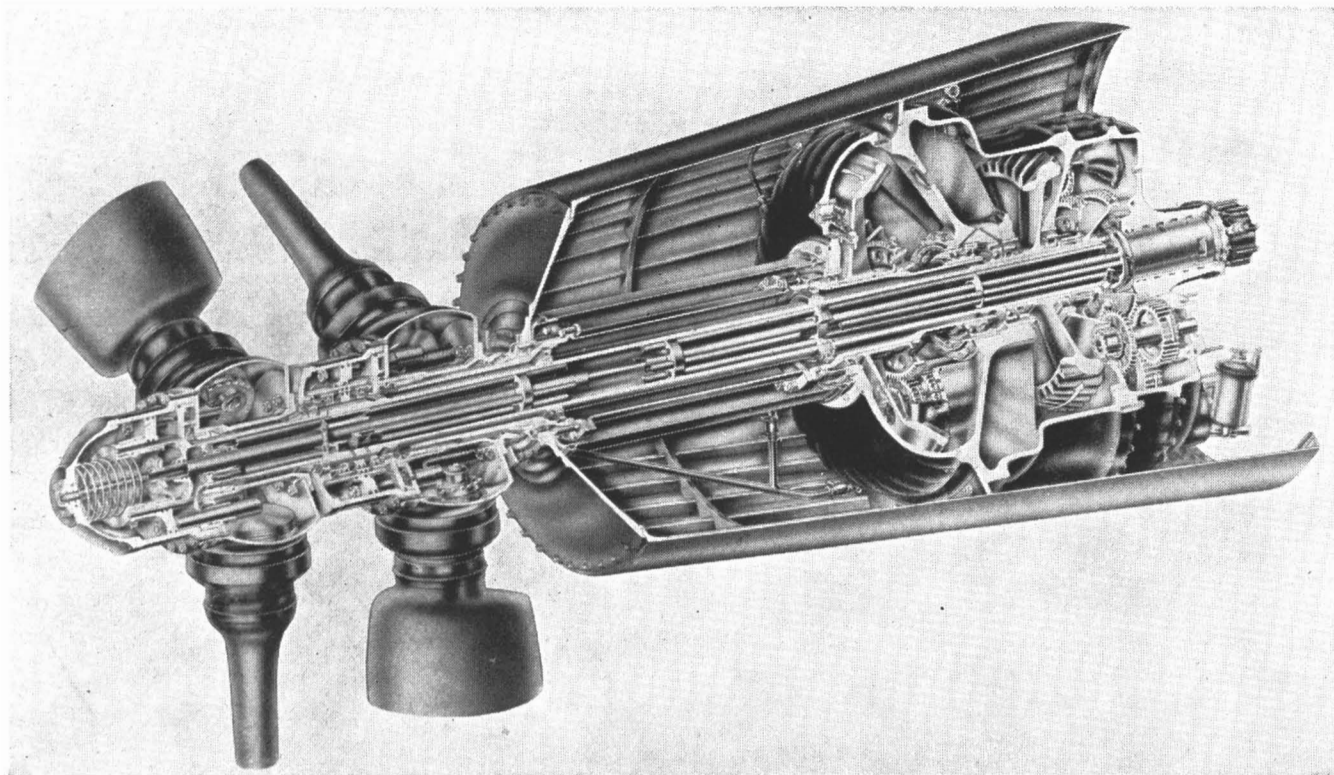


Fig. 22.—Dual-reduction gear and propeller hubs
Perspective section

Engine cooling was proved for the first time on this rig, and was found to be completely adequate. In fact, extended running under the most severe conditions, even during hot summer weather, was possible without recourse to the supplementary cooling fans provided in case of need.

This part of the programme culminated in the official 150 hours 'type test' to the Air Registration Board's requirements for civil aircraft. The test was carried out, for the greater part, in 10-hour periods at all running conditions encountered during take-off and in flight and including overspeeding. Incidental running brought the total power unit running time for this test to over 180 hours, all of which was carried out under the technical supervision of the Air Registration Board's resident engineer.

In all, some 415 hours' running have been accomplished on this test stand.

Fire Protection

Probably one of the most feared hazards of flying is fire in the air. With its high unit and gas temperatures, the engine is the most obvious source of fire, so effective means of detecting and extinguishing fire had to be incorporated.

Each engine cell in the leading edge of the wing has fire-proof stainless-steel linings to prevent a fire burning its way through. Some fifteen flame detector switches are installed in strategic positions around the engine and on the firewalls. These switches are looped into a common circuit

associated with a warning at the flight engineers' station.

Supplies of methyl bromide extinguishing

medium are carried in cylinders within the wing. These are piped to sprayer rings in front of and behind each engine, and to the engine air intakes. In the event of a fire warning, the engineer carries out the following sequence of operations:

- (a) Initiates propeller feathering.
- (b) Closes air inlet and oil-cooler duct shutters, and operates injector-fuel cut off (stopping engine).
- (c) Closes fuel and oil cocks.
- (d) Closes cooling-air outlet flaps.
- (e) Operates fire-extinguisher system.

Experience has proved the need to shut down the engine completely before releasing the flood of fire-extinguishing medium. The 'Centaurus' 20 installation has an advantage over normal installations in that the cooling-air supply can be shut off completely, so preventing excessive loss of methyl bromide.

The last test carried out on the Phase 2 rig proved the efficacy of the fire precautions. For this test a really pessimistic engine failure was postulated in which a cylinder was blown off. In this event flames from the broken exhaust manifold could ignite the petrol-air mixture issuing from the broken induction pipe, and the oil spray thrown from the crankcase.

This rather drastic effect was obtained by installing two special burners on the right-hand engine, one between the cylinders and the other in a position to direct the flames on to the petrol

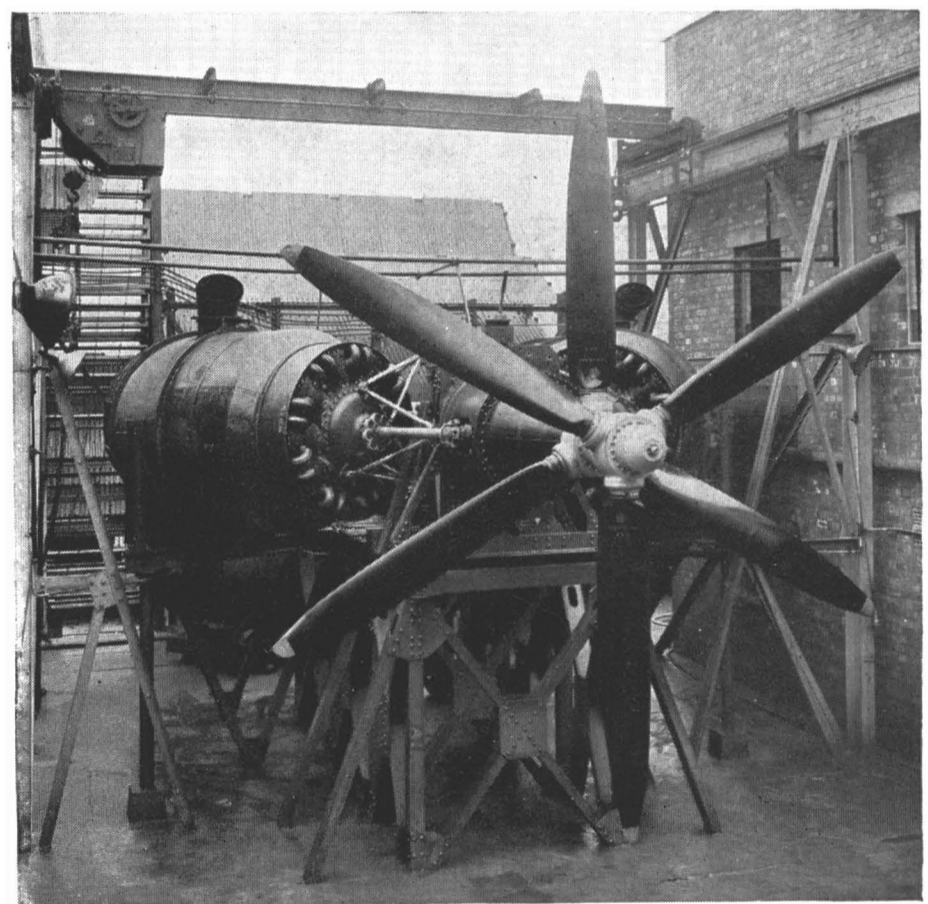


Fig. 24.—Phase I test stand

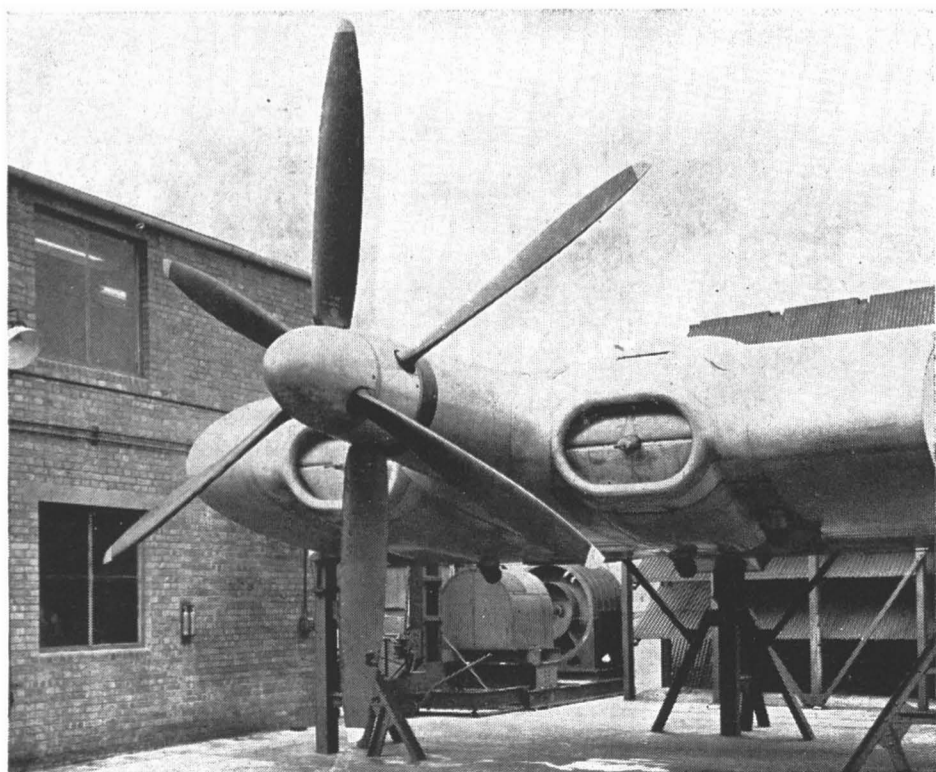


Fig. 25.—Phase 2 test stand

pump and injector. Two separately driven pumps supplied petrol and hot oil to the burners at the combined rate of 240 gal. per hr. front, and 120 gal. per hr. rear. Electrical means were provided to initiate the fires. Both engines were started and run at take-off conditions, then the oil supply was turned on to flood the compartment with hot oil. After 30 seconds the petrol was turned on and then ignited. As soon as the fire was observed externally the fire drill was put into operation. The left-hand engine was meanwhile kept running at take-off conditions to simulate flight slip-stream effects.

The time interval between observing the 'fire' and the 'fire-out' signal was 36.1 seconds.

Within a few minutes of extinguishing the fire, both engines were again started and run up to take-off condition without incident.

Acknowledgment

In conclusion the author would like to express his thanks to the management of the Bristol Aeroplane Company Ltd., for permission to publish this paper.

The Quadrilateral 'Shear' Panel

The Peculiar Stressing Problems Arising in the Structure of the Non-Rectangular Swept Wing

By S. J. Garvey, B.Sc., D.I.C., A.F.R.Ae.S.

1. Introduction

Among the problems introduced by swept wings is that of the non-rectangular panel in equilibrium under loading applied tangentially along its edges. The present article examines the state of stress in a general uniform quadrilateral panel and, for the benefit of stiffness calculations, the strain energy stored in it. Stable conditions are assumed.

The problem of replacing such a panel by 'diamond' bracing is also treated.

2. Equilibrium of the Panel

Let $ABCD$ (FIG. 1) be a flat quadrilateral plate in equilibrium under forces F_1, F_2, F_3, F_4 applied along the sides AB, BC, CD, DA respectively. It is required to find the ratios of the forces.

Draw DE parallel to CA to meet BA produced in E . Draw EF parallel to BC to meet CD produced in F . Then $ADFE$ is a force polygon for the F 's.

For, since the resultant of F_1 and F_4 must lie along AC in order to balance the resultant of F_2 and F_3 , the triangle EAD gives the relation of F_1 to F_4 . Similarly the triangle DFE gives the relation of F_2 to F_3 , and since ED represents the resultant of both pairs of forces, it follows that F_1, F_2, F_3 and F_4 are proportional respectively to the lengths EA, FE, DF and AD .

3. Distribution of Force along the Edges

Let DA and CB meet in P , and AB and DC in Q (FIG. 2).

Then the assumption is made that across any section of the panel through P or Q , the force is entirely tangential. This assumption clearly satisfies the edge conditions and, as will be seen, also satisfies the condition for equilibrium of infinitesimal elements.

Let $\bar{s}_1, \bar{s}_2, \bar{s}_3, \bar{s}_4$ be the mean loadings (force per unit length) on the respective sides, so that $\bar{s}_1 = F_1/AB$, etc.

Let PLM be any section through P , and let \bar{s}_P be the mean loading on LM . Then defining angles $\alpha, \beta, \gamma, \delta, \phi$ as in FIG. 2, from the equilibrium of the part $LBCM$, taking moments about Q :

$$s_P.LM.PQ \sin \phi = \bar{s}_2.BC.PQ \sin \alpha$$

i.e. $\bar{s}_P = \bar{s}_2 \frac{BC \sin \alpha}{LM \sin \phi}$

$$= \bar{s}_2 \frac{\sin^2 \alpha \sin(\beta + \phi) \sin(\delta + \phi)}{\sin^2 \phi \sin(\alpha + \beta) \sin(\alpha + \delta)}$$

by trigonometry

$$= \bar{s}_2 \frac{\sin(\beta + \phi) \sin(\delta + \phi) \sin \alpha \sin \beta \sin \alpha \sin \delta}{\sin \beta \sin \phi \sin \delta \sin \phi \sin(\alpha + \beta) \sin(\alpha + \delta)}$$

$$= \bar{s}_2 \frac{(\cot \beta + \cot \phi)(\cot \delta + \cot \phi)}{(\cot \alpha + \cot \beta)(\cot \alpha + \cot \delta)}$$

If we drop perpendiculars from L, M, B, C to PQ , and denote their respective lengths by p_L, p_M, p_B, p_C , then

$$\cot \beta + \cot \phi = \frac{PQ}{p_L}, \quad \cot \delta + \cot \phi = \frac{PQ}{p_M}$$

$$\cot \alpha + \cot \beta = \frac{PQ}{p_B}, \quad \cot \alpha + \cot \delta = \frac{PQ}{p_C}$$

$$\therefore \bar{s}_P = \bar{s}_2 \frac{p_B p_C}{p_L p_M} \dots \dots \dots (1)$$

Now consider the equilibrium of an infinitesimal strip bounded by adjacent sections $PLM, PL'M'$, where angle $L'PL = \delta\phi$.

Let the local loading on LL' be s_1 and on MM' be s_3 .

Then taking moments about M' for the strip:

$$s_1.PL\delta\phi.LM = \bar{s}_P.LM.PM\delta\phi$$

neglecting terms of the second order.

$$\therefore s_1 = \bar{s}_P \frac{PM}{PL} = \bar{s}_P \frac{p_M}{p_L} \text{ by similar triangles}$$

\therefore using (1),

$$s_1 = \bar{s}_2 \frac{p_B p_C}{p_L^2} \dots \dots \dots (2)$$

Similarly, taking moments about L' for the strip.

$$s_3 = \bar{s}_2 \frac{p_B p_C}{p_M^2}$$

Similarly also if QNR be any section through Q , where angle $NQP = \psi$, the local loadings at N and R are given by

$$s_2 = \bar{s}_1 \frac{p_A p_B}{p_N^2}$$

$$s_4 = \bar{s}_1 \frac{p_A p_B}{p_R^2}$$

Now by taking moments about D for the whole panel, we have

$$\frac{\bar{s}_1}{s_2} = \frac{\Delta BDC}{\Delta BDA} = \frac{CX}{XA}$$

where X is the intersection of AC and BD .

If AC produced meets PQ produced in S , then $AXCS$ is a harmonic range, so that

$$\frac{CX}{XA} = \frac{CS}{SA} = \frac{p_C}{p_A} \text{ by similar triangles.}$$

$$\text{Hence } \frac{\bar{s}_1}{s_2} = \frac{p_C}{p_A}, \text{ or}$$

$$\bar{s}_1 p_A p_B = \bar{s}_2 p_B p_C, = \text{similarly } \bar{s}_3 p_C p_D = \bar{s}_4 p_D p_A \quad (3)$$

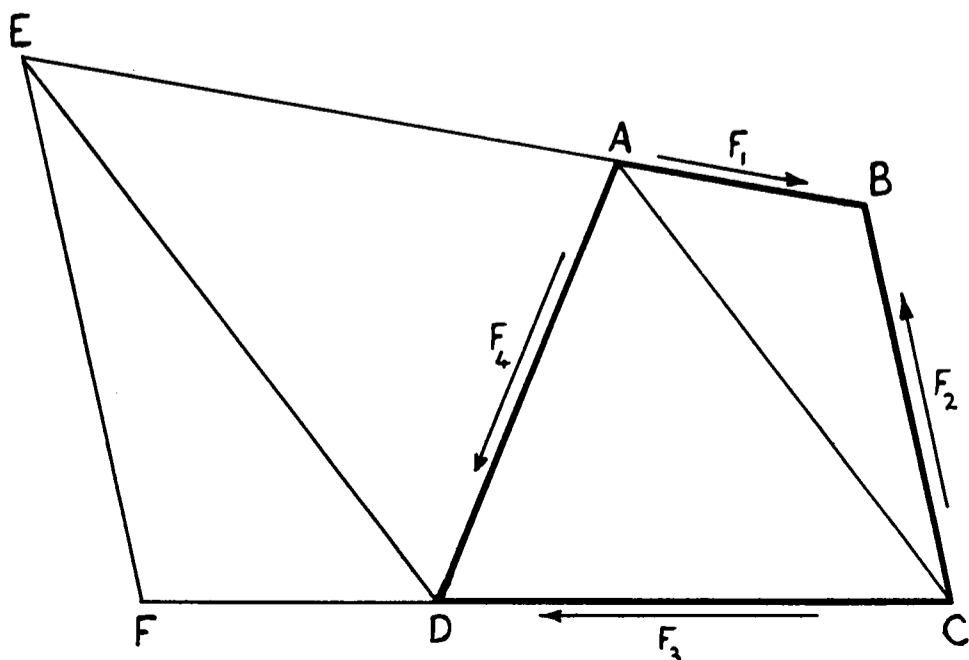


Fig. 1. left

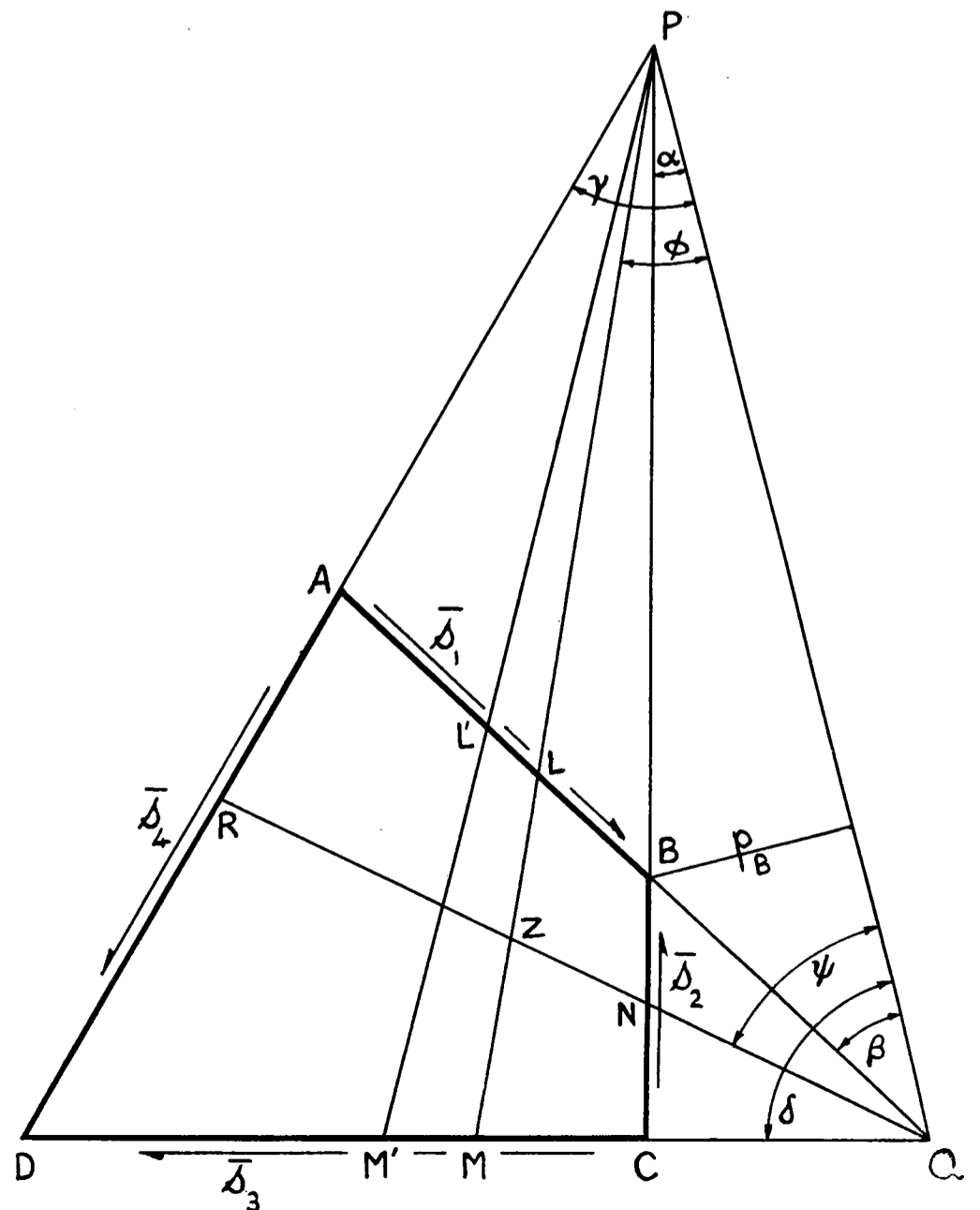


Fig. 2. right

It follows that the local loading at any point on the boundary of the panel is inversely proportional to the square of the perpendicular from that point to the line PQ .

4. Internal Loading

Take any point Z in the panel, and let PLM , QNR be the sections through P and Q respectively which pass through it.

Let s_P be the local loading at Z in the direction LM , and let s_Q be the local loading at Z in the direction NR .

Then applying the conclusion of section 3 to the portion $LBCM$, we see that

$$s_P = s_2 \frac{P_{BPC}}{P_Z^2}$$

and from the portion $ABNR$,

$$s_Q = s_1 \frac{P_{APB}}{P_Z^2}$$

Hence from equation (3).

$$s_P = s_Q \dots \dots \dots (4)$$

which is the condition for the equilibrium of an infinitesimal parallelogram at Z with sides parallel to ZL and ZN .

Thus we may generalize the conclusion of Section (3) and say that

The local loading s at any point z in, or on the boundary of, the panel is the same in the directions ZP and ZQ , and is given by:

$$s = \frac{s_1 P_{APB}}{P_Z^2} = \frac{s_2 P_{BPC}}{P_Z^2} = \frac{s_3 P_{CPD}}{P_Z^2} = \frac{s_4 P_{DDA}}{P_Z^2} \dots \dots \dots (5)$$

where p is the length of the perpendicular from the point denoted by the suffix to the line PQ .

5. The Parallelogram

In the case of a parallelogram, PQ recedes to infinity, and the loading s is therefore uniform and the same on all edges, and on all sections parallel with the edges.

If the angle of the parallelogram is θ (FIG. 3) and the thickness of the panel is t , then by taking a section EF normal to AB and considering the equilibrium of the part $AEFD$, we see that the panel is in a state of stress equivalent to a shear stress $\frac{s}{t}$ and a direct stress $\frac{2s}{t} \cot \theta$.

The strain energy U of the panel is therefore given by

$$U = \left(\frac{s^2}{2Gt^2} + \frac{4s^2 \cot^2 \theta}{2Et^2} \right) \times \text{Volume}$$

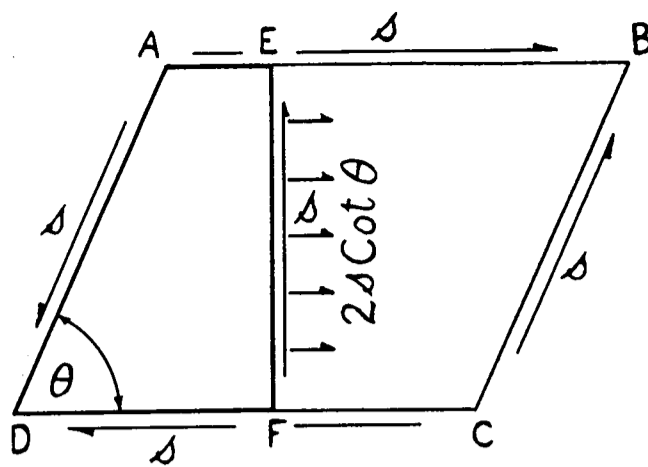


Fig. 3.

$$= \frac{s^2}{2Gt^2} \left(1 + \frac{2}{1+\nu} \cot^2 \theta \right) \times \text{Volume} \dots (6)$$

where ν is Poisson's ratio and G the shear modulus.

The principal direct stresses are

$$\frac{s}{t} \cot \theta \pm \sqrt{\frac{s^2 \cot^2 \theta}{t^2} + \frac{s^2}{t^2}}$$

i.e. $\frac{s}{t} \cot \theta$ and $-\frac{s}{t} \tan \theta$; their directions may be

shown to be parallel to the internal and external bisectors respectively of the angle θ .

6. Strain Energy of the Quadrilateral Panel

Consider an infinitesimal element of the panel bounded by sections ϕ , $\phi + \delta\phi$ through P , and sections ψ , $\psi + \delta\psi$ through Q . It is a parallelogram to the first order, of angle $(\phi + \psi)$, and (writing $PQ = l$) its area is

$$\frac{l \sin \phi \delta\psi}{\sin^2(\phi + \psi)} \times \frac{l \sin \psi \delta\phi}{\sin^2(\phi + \psi)} \times \sin(\phi + \psi) = \frac{l^2 \delta\phi \delta\psi}{(\cot \phi + \cot \psi)^2 \sin^2 \phi \sin^2 \psi}$$

Also, by (5), the loading round its edges is given by

$$s = s_1 \frac{P_{APB} (\cot \phi + \cot \psi)^2}{l^2}$$

Therefore, by (6), strain energy of element is given by

$$\delta U = \frac{s_1^2 P_{APB}^2 P_{BPC}^2 (\cot \phi + \cot \psi)}{2l^2 t G \sin^2 \phi \sin^2 \psi} \left\{ 1 + \frac{2}{1+\nu} \frac{(\cot \phi \cot \psi - 1)^2}{(\cot \phi + \cot \psi)^2} \right\} \delta\phi \delta\psi$$

The strain energy of the panel is thus

$$U = \frac{s_1^2 s_2^2 P_{APB} P_{BPC} P_{CPD}}{2l^2 t G} \int_{\beta}^{\delta} \int_{\alpha}^{\gamma} \left\{ (\cot \phi + \cot \psi) + \frac{2}{(1+\nu)} \frac{(\cot \phi \cot \psi - 1)^2}{(\cot \phi + \cot \psi)} \right\} \frac{d\phi d\psi}{\sin^2 \phi \sin^2 \psi}$$

using (3).

The double integration may be effected by the substitution $\cot \phi = x$, $\cot \psi = y$.

Writing for conciseness $\cot \alpha = a$, $\cot \beta = b$, $\cot \gamma = c$, $\cot \delta = d$, we find

$$U = \frac{s_1^2 s_2^2 P_{APB} P_{BPC} P_{CPD}}{2l^2 t G} \left\{ \frac{1}{2} \frac{(a-c)(b-d)(a+b+c+d)}{2} + \frac{2}{(1+\nu)} \cdot F \right\} \dots \dots \dots (7)$$

where

$$F = \left[(a+b) + \frac{2}{3}(a^3+b^3) + \frac{1}{5}(a^5+b^5) \right] \log(a+b) + \left[(c+d) + \frac{2}{3}(c^3+d^3) + \frac{1}{5}(c^5+d^5) \right] \log(c+d) - \left[(b+c) + \frac{2}{3}(b^3+c^3) + \frac{1}{5}(b^5+c^5) \right] \log(b+c) - \left[(d+a) + \frac{2}{3}(d^3+a^3) + \frac{1}{5}(d^5+a^5) \right] \log(d+a) + \frac{1}{10}(a^2-c^2)(b^3-d^3) + \frac{1}{10}(b^2-d^2)(a^3-c^3) - \frac{1}{5}(a-c)(b^4-d^4) - \frac{1}{5}(b-d)(a^4-c^4) - \frac{2}{3}(a-c)(b-d)(a+b+c+d) \dots \dots \dots (8)$$

The area of the quadrilateral is

$$\frac{l}{2} (p_B + p_D - p_A - p_C), \text{ which reduces to}$$

$$\frac{P_{APB} P_{BPC} P_{CPD}}{2l^2} (a-c)(b-d)(a+b+c+d)$$

on substituting $p_A = \frac{l}{b+c}$, etc., so that U may be expressed in terms of the volume of the panel.

7. Principal Direct Stresses

Applying the result of section 5, the principal direct stresses at the point Z defined by the (Concluded on p. 144)

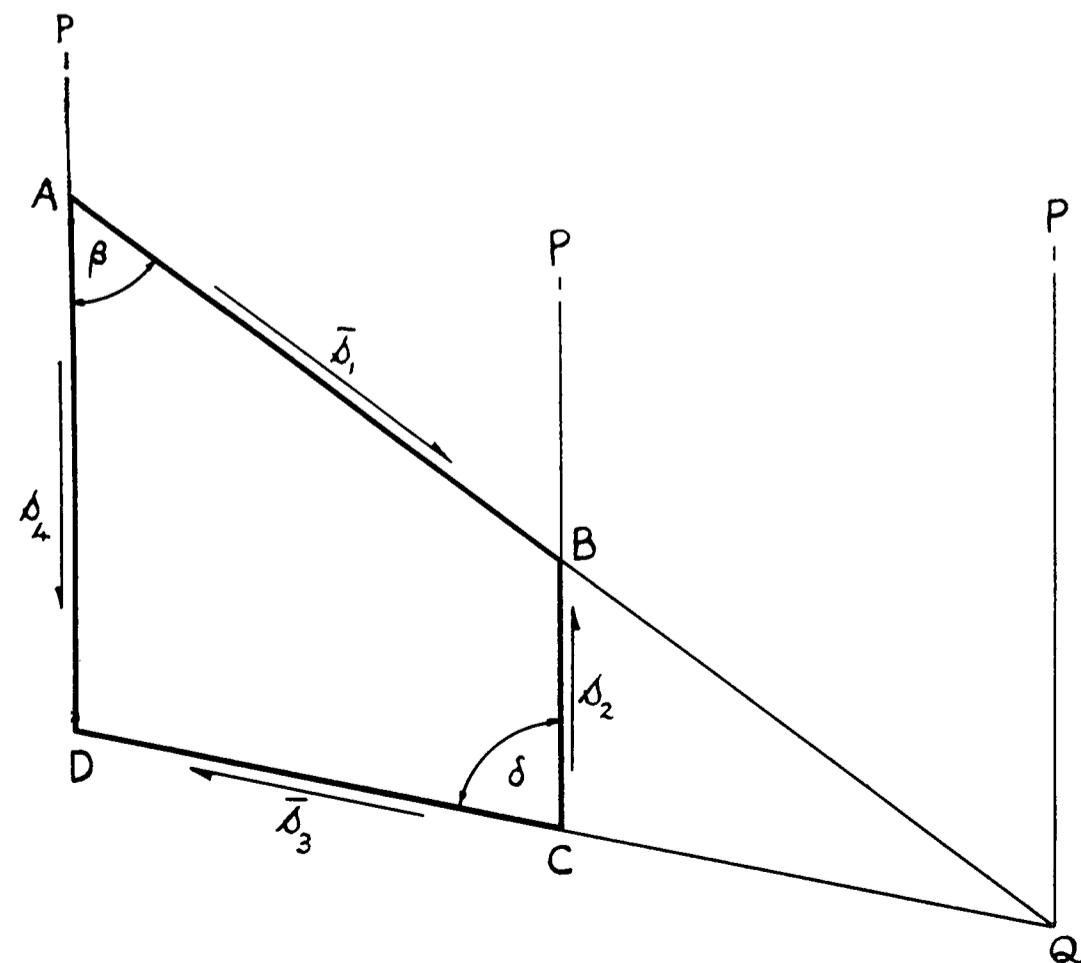


Fig. 4.

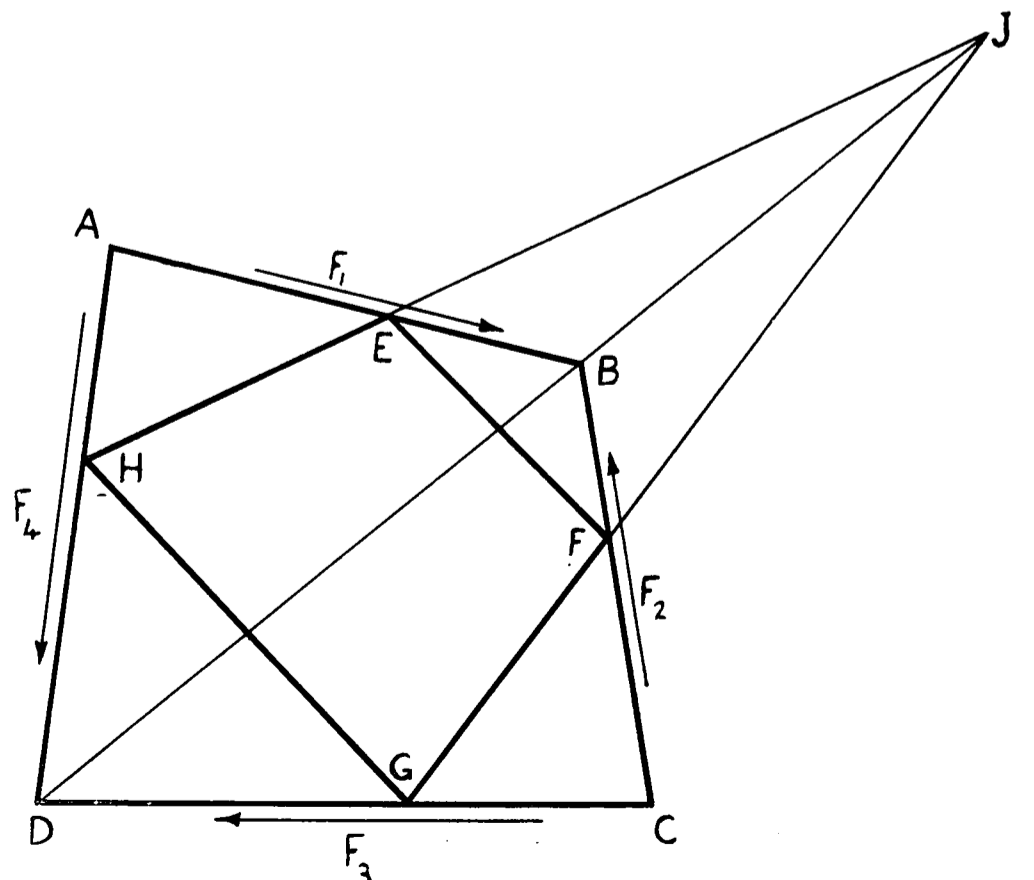


Fig. 5.

An Application of the Escalator Process

Solution Thereby of Quasi-Hermitian Frequency Equations Encountered in Specific Practical Problems

By J. Morris

1. Introduction

IN the course of the analytical treatment of certain practical problems, in particular the whirling of contra-rotating propeller systems and the mechanical vibration of aircraft, two somewhat unusual species of Lagrangian type frequency equations were encountered and it was considered expedient to adapt the Escalator¹ process to their solution. The orthogonality of the modes of Lagrangian frequency equations is the fundamental feature of the various processes which have been devised in recent years to solve such equations. It is for instance the primary artifice in Duncan and Collar's matrix iteration² solution and the cardinal device in the Morris and Head Escalator¹ process. It is here shown that the same basic artifice is readily applicable to the kind of equations referred to above. It may be recalled that the Escalator process is based essentially on the successive introduction or elimination of each of the variables involved by definite self-contained stages in which the roots and modes of say a fourth-order set of equations are obtained in terms of those of the preceding third-order equations and *vice-versa*.

2.1 Equations of Hermitian Form

These are exemplified as follows:

$$\begin{aligned} (a_{11} \pm \lambda)x + a_{12}y + a_{13}z &= 0, \dots \dots \dots (1) \\ a_{12}x + (a_{22} \pm \lambda)y + a_{23}z &= 0, \dots \dots \dots (2) \\ a_{13}x + a_{23}y + (a_{33} \pm \lambda)z &= 0, \dots \dots \dots (3) \end{aligned}$$

where the sign before the λ in any particular equation may be plus or minus.

First it is to be observed that if all these signs are the same and the a_{rs} 's are real then the λ or latent roots of the equations will all be real. Secondly if these signs are not all the same the roots will still be real provided the a_{rs} 's are coefficients of a positive definite. Thirdly if there are n equations in p of which there are positive signs before the λ 's and in the remaining $(n-p)$ there are negative signs before the λ 's then if the a_{rs} 's are coefficients of a positive definite there will be p negative roots and $(n-p)$ positive roots of the equations.

This follows from the fact that since the a_{rs} 's are coefficients of a positive definite, there is separation of the reciprocals of the λ roots by successive orders constituting the equations. Thus the reciprocal of the root of the first order, viz.

$$(a_{11} \pm \lambda)x = 0 \dots \dots \dots (4)$$

separates the reciprocals of the two roots of the second order equations, viz.

$$\left. \begin{aligned} (a_{11} \pm \lambda)x + a_{12}y &= 0, \\ a_{12}x + (a_{22} \pm \lambda)y &= 0, \end{aligned} \right\} \dots \dots \dots (5)$$

and the reciprocals of these two roots in turn separate those for the third-order equations (1), (2), (3).

2.2 Orthogonality of the Modes

Let us consider the particular case of the four following equations, viz.:

$$(a_{11} - \lambda)x + a_{12}y + a_{13}z + a_{14}u = 0, \dots \dots \dots (6)$$

Summary

The escalator process is shown to be easily applicable to certain frequency equations of Hermitian character which have been encountered in such problems as the whirling of contra propeller systems and the mechanical vibration of an aircraft.

REFERENCES TO LITERATURE

- (1) Morris and Head. The 'Escalator' Process for the solution of Lagrangian Frequency Equations. *Phil. Mag.*, Vol. 35 (1944).
- (2) Duncan and Collar. On a Method for the Solution of Oscillation Problem by Matrices. *Phil. Mag.*, Vol. 17 (1934).

$$a_{12}x + (a_{22} - \lambda)y + a_{23}z + a_{24}u = 0, \dots \dots \dots (7)$$

$$a_{13}x + a_{23}y + (a_{33} + \lambda)z + a_{34}u = 0, \dots \dots \dots (8)$$

$$a_{14}x + a_{24}y + a_{34}z + (a_{44} + \lambda)u = 0, \dots \dots \dots (9)$$

Let λ_r ($r=1, 2, 3, 4$) be a root of these equations and let x_r, y_r, z_r, u_r be its associated modes. Multiply (6) by x_r , (7) by y_r , (8) by z_r , (9) by u_r and add. We obtain

$$(\lambda_r - \lambda)(xx_r + yy_r - zz_r - uu_r) = 0, \dots \dots \dots (10)$$

Thus we have the following orthogonal modal relation, viz.:

$$x_r x_s + y_r y_s - z_r z_s - u_r u_s = 0, \dots \dots \dots (11)$$

in which r is not equal to s .

Further since the ratios only of the modes are ascertainable from the original equations we may arrange for

$$x_r^2 + y_r^2 - z_r^2 - u_r^2 = 1, \dots \dots \dots (12)$$

in which circumstances we call the modes rectified modes.

We notice that as a consequence of the modal relations (11) and (12) that

$$\begin{aligned} \sum x_r^2 = 1, \sum y_r^2 = 1, \sum z_r^2 = -1, \sum u_r^2 = -1; \\ \sum x_r y_r = 0, \sum x_r z_r = 0, \sum x_r u_r = 0, \\ \sum y_r z_r = 0, \sum y_r u_r = 0, \sum z_r u_r = 0, \dots \dots \dots (13) \end{aligned}$$

in which $r=1, 2, 3, 4$;

otherwise the procedure is as for the ordinary Hermitian equations. It may be noted that although for real roots the relative modes are real, the corresponding rectified modes may be pure imaginaries.

3.1 Quasi-Hermitian Frequency Equations

As an illustration of equations of this type let us consider the following, viz.:

$$(a_{11} - \lambda)x + a_{12}y + a_{13}\lambda z = 0, \dots \dots \dots (1)$$

$$a_{12}x + (a_{22} - \lambda)y + a_{23}\lambda z = 0, \dots \dots \dots (2)$$

$$a_{13}x + a_{23}y + \left(\frac{1}{\lambda} - a_{33}\right)\lambda z = 0, \dots \dots \dots (3)$$

Let λ_r ($r=1, 2, 3$) be a root of these three equations and let $x_r, y_r, \lambda_r z_r$ be its associated modes. Multiply (1) by x_r , (2) by y_r , (3) by $\lambda_r z_r$, and add. We obtain

$$(\lambda_r - \lambda)(xx_r + yy_r + zz_r) = 0, \dots \dots \dots (4)$$

Hence if r is not equal to s we have the orthogonal modal relationship

$$x_r x_s + y_r y_s + z_r z_s = 0; \dots \dots \dots (5)$$

and since the ratios only of the modes are

ascertainable from the equations we may arrange for

$$x_r^2 + y_r^2 + z_r^2 = 1, \dots \dots \dots (6)$$

Modes subject to the relation (6) for the particular case correspond to the rectified modes in the Hermitian case.

3.2 The Escalator Equation

Let λ_r ($r=1, 2$) be a root of the equations (1), (2), with $z=0$, and let x_r, y_r be its associated rectified modes. Multiply equations (1), (2) respectively by x_r, y_r , and add. We obtain

$$(\lambda_r - \lambda)(xx_r + yy_r) + p_r \lambda z = 0, \dots \dots \dots (7)$$

$$\text{where } p_r = a_{13}x_r + a_{23}y_r \dots \dots \dots (8)$$

$$\text{Now } \sum_1^2 p_r (xx_r + yy_r) = a_{13}x + a_{23}y, \dots \dots \dots (9)$$

$$\text{which in turn by (3) is } = -\left(\frac{1}{\lambda} - a_{33}\right)\lambda z, \dots \dots \dots (10)$$

Hence we derive from (7) the escalator equation

$$\sum_1^2 \frac{p_r^2}{(\lambda_r - \lambda)} = \left(\frac{1}{\lambda} - a_{33}\right) \dots \dots \dots (11)$$

For the modes corresponding to a root λ we have

$$\frac{x}{\lambda z} = -\sum_1^2 \frac{p_r x_r}{(\lambda_r - \lambda)}, \dots \dots \dots (12)$$

$$\frac{y}{\lambda z} = -\sum_1^2 \frac{p_r y_r}{(\lambda_r - \lambda)}, \dots \dots \dots (13)$$

$$\text{Thus } \frac{x^2 + y^2}{\lambda^2 z^2} = \sum_1^2 \frac{p_r^2}{(\lambda_r - \lambda)^2} \dots \dots \dots (14)$$

To rectify these modes we arrange for

$$x^2 + y^2 + z^2 = 1, \dots \dots \dots (15)$$

$$\text{or } \left[\sum_1^2 \frac{p_r^2 \lambda^2}{(\lambda_r - \lambda)^2} + 1 \right] = \frac{1}{z^2} \dots \dots \dots (16)$$

3.3 The Escalator in Reverse

Let λ_r ($r=1, 2, 3$) be a root of the equations (1), (2), (3), and let $x_r, y_r, \lambda_r z_r$ be its associated rectified modes, i.e. modes subjected in this case to the condition

$$x_r^2 + y_r^2 + z_r^2 = 1, \dots \dots \dots (17)$$

Given these to find the escalator equation and expressions for the corresponding modes of the equations (1), (2), with $z=0$. Multiply these last two equations, so modified, by x_r, y_r , respectively, and add. We obtain

$$\begin{aligned} (a_{11}x_r + a_{12}y_r - \lambda x_r)x \\ + (a_{12}x_r + a_{22}y_r - \lambda y_r)y, \dots \dots \dots (18) \end{aligned}$$

$$\text{Now } (a_{11} - \lambda_r)x_r + a_{12}y_r + a_{13}\lambda_r z_r = 0, \dots \dots \dots (19)$$

$$\text{and } a_{12}x_r + (a_{22} - \lambda_r)y_r + a_{23}\lambda_r z_r = 0, \dots \dots \dots (20)$$

Hence (18) may be written

$$(\lambda_r - \lambda)(xx_r + yy_r) = p_r \lambda_r z_r, \dots \dots \dots (21)$$

$$\text{where } p = (a_{13}x + a_{23}y) \dots \dots \dots (22)$$

Thus in virtue of the orthogonal properties of the rectified modes the required escalator equation will be given by

$$\sum_1^3 \frac{\lambda_r z_r^2}{(\lambda_r - \lambda)} = 0; \dots \dots \dots (23)$$

and the modes corresponding to a root λ by

$$\frac{x}{p} = \sum_1^3 \frac{\lambda_r x_r z_r}{(\lambda_r - \lambda)}, \dots \dots \dots (24)$$

$$\frac{y}{p} = \sum_1^3 \frac{\lambda_r y_r z_r}{(\lambda_r - \lambda)}, \dots \dots \dots (25)$$

For rectification of these modes we have

$$\frac{x^2 + y^2}{p^2} = \sum_1^3 \frac{\lambda_r^2 z_r^2}{(\lambda_r - \lambda)^2} \dots (26)$$

$$\text{and thus } \frac{1}{p^2} = \sum_1^3 \frac{\lambda_r^2 z_r^2}{(\lambda_r - \lambda)^2} \dots (27)$$

3.4 General Case of the Quasi-Hermitian Equations

These will be of the form

$$(a_{11} - \lambda)x + a_{12}y + a_{13}\lambda z + a_{14}\lambda u = 0, \dots (28)$$

$$a_{12}x + (a_{22} - \lambda)y + a_{23}\lambda z + a_{24}\lambda u = 0, \dots (29)$$

$$a_{13}x + a_{23}y + \left(\frac{1}{\lambda} - a_{33}\right)\lambda z + a_{34}\lambda u = 0, \dots (30)$$

$$a_{14}x + a_{24}y + a_{34}\lambda z + \left(\frac{1}{\lambda} - a_{44}\right)\lambda u = 0, \dots (31)$$

in which we have ordinary Hermitian latent root equations up to the p th the order, say, and of the type like (30) and (31) for subsequent orders.

It will be sufficient for our purpose if we illustrate the procedure for the four equations (28), (29), (30), (31).

First we consider the equations (28), (29), (30), with $u=0$. Let λ_r ($r=1, 2, 3$) be a root of such equations and let $x_r, y_r, \lambda_r z_r$, be its associated rectified modes. Now multiply (28) by x_r , (29) by y_r , (30) by $\lambda_r z_r$, and add. We obtain

$$(\lambda_r - \lambda)(xx_r + yy_r + zz_r) + (a_{14}x_r + a_{24}y_r + a_{34}\lambda_r z_r)\lambda u = 0, \dots (32)$$

$$\text{or } (\lambda_r - \lambda)[xx_r + yy_r + (z + a_{34}\lambda u)z_r] + p_r \lambda u = 0, \dots (33)$$

$$\text{where } p_r = a_{14}x_r + a_{24}y_r + a_{34}\lambda_r z_r. \dots (34)$$

Hence it follows from the orthogonal properties of the rectified modes that

$$\begin{aligned} \sum p_r [xx_r + yy_r + (z + a_{34}\lambda u)z_r] \\ = a_{14}x + a_{24}y + a_{34}\lambda z + a_{34}^2 \lambda u \\ = \left[-\left(\frac{1}{\lambda} - a_{44}\right) + a_{34}^2 \lambda \right] \lambda u \dots (35) \end{aligned}$$

Thus the escalator equation pertaining to the four equations (28), (29), (30), (31), will be

$$\sum_1^3 \frac{p_r^2}{(\lambda_r - \lambda)} = \left(\frac{1}{\lambda} - a_{44}\right) - a_{34}^2 \lambda; \dots (36)$$

and the corresponding modes will be given by

$$\frac{x}{\lambda u} = -\sum_1^3 \frac{p_r x_r}{(\lambda_r - \lambda)}, \dots (37)$$

$$\frac{y}{\lambda u} = -\sum_1^3 \frac{p_r y_r}{(\lambda_r - \lambda)}, \dots (38)$$

$$\frac{z + a_{34}\lambda u}{\lambda u} = -\sum_1^3 \frac{p_r z_r}{(\lambda_r - \lambda)}. \dots (39)$$

For rectification of these modes we have

$$\left[\sum_1^3 \frac{p_r^2}{(\lambda_r - \lambda)^2} + 2a_{34} \sum_1^3 \frac{p_r z_r}{(\lambda_r - \lambda)} + a_{34}^2 \right] \lambda^2 + 1 = \frac{1}{u^2} \dots (40)$$

Next let the equations (28), (29), (30), (31), be bordered to form the fifth-order set of equations

with $\left(\frac{1}{\lambda} - a_{55}\right)\lambda v$ at the bottom right-hand corner. If λ_r ($r=1, 2, 3, 4$) is a root of the unbordered equations and $x_r, y_r, \lambda_r z_r, \lambda_r u_r$ are its associated rectified modes, then we find the escalator equation for the fifth-order will be

$$\sum_1^4 \frac{p_r^2}{(\lambda_r - \lambda)} = \left(\frac{1}{\lambda} - a_{55}\right) - (a_{35}^2 + a_{45}^2)\lambda, \dots (41)$$

$$\text{where } p_r = a_{15}x_r + a_{25}y_r + a_{35}\lambda_r z_r + a_{45}\lambda_r u_r, \dots (42)$$

and for the modes corresponding to a root λ

$$\frac{x}{\lambda v} = -\sum_1^4 \frac{p_r x_r}{(\lambda_r - \lambda)}, \frac{y}{\lambda v} = -\sum_1^4 \frac{p_r y_r}{(\lambda_r - \lambda)}, \dots (43)$$

$$\frac{z + a_{35}\lambda v}{\lambda v} = -\sum_1^4 \frac{p_r z_r}{(\lambda_r - \lambda)}, \dots (44)$$

$$\frac{u + a_{45}\lambda v}{\lambda v} = -\sum_1^4 \frac{p_r u_r}{(\lambda_r - \lambda)}. \dots (45)$$

For rectification of these modes we have

$$\left[\sum_1^4 \frac{p_r^2}{(\lambda_r - \lambda)^2} + 2 \left\{ a_{35} \sum_1^4 \frac{p_r z_r}{(\lambda_r - \lambda)} + a_{45} \sum_1^4 \frac{p_r u_r}{(\lambda_r - \lambda)} \right\} + (a_{35}^2 + a_{45}^2) \right] \lambda^2 + 1 = \frac{1}{v^2}. \dots (46)$$

For the Escalator in reverse in this case let λ_r ($r=1, 2, 3, 4, 5$) be a root of the fifth-order equations treated above, and let $x_r, y_r, \lambda_r z_r, \lambda_r u_r, \lambda_r v_r$, be its associated rectified modes. To find the solution of the equations (28), (29), (30), (31) in terms of these quantities, we have for (28) x_r , (29) y_r , (30) $\lambda_r z_r$, (31) $\lambda_r u_r$, by addition

$$(\lambda_r - \lambda)(xx_r + yy_r + zz_r + uu_r) = p_r \lambda_r v_r, \dots (47)$$

$$\text{where } p = a_{15}x + a_{25}y + a_{35}\lambda z + a_{45}\lambda u. \dots (48)$$

Thus the Escalator equation in reverse from the fifth- to the fourth-order will be

$$\sum_1^5 \frac{\lambda_r v_r^2}{(\lambda_r - \lambda)} = 0. \dots (49)$$

The modes corresponding to a root λ will be given by

$$x = \sum_1^5 \frac{p_r \lambda_r x_r v_r}{(\lambda_r - \lambda)}, \dots (50)$$

$$y = \sum_1^5 \frac{p_r \lambda_r y_r v_r}{(\lambda_r - \lambda)}, \dots (51)$$

$$z = \sum_1^5 \frac{p_r \lambda_r z_r v_r}{(\lambda_r - \lambda)}, \dots (52)$$

$$u = \sum_1^5 \frac{p_r \lambda_r u_r v_r}{(\lambda_r - \lambda)}, \dots (53)$$

and for their rectification

$$x^2 + y^2 + z^2 + u^2 = 1, \dots (54)$$

$$\text{and thus } \frac{1}{p^2} = \sum_1^5 \frac{p_r^2 \lambda_r^2 v_r^2}{(\lambda_r - \lambda)^2}. \dots (55)$$

3.5 Special case where principal diagonal terms may be $\frac{1}{\lambda}$

Thus for example consider the case

$$(a_{11} - \lambda)x + a_{12}y + a_{13}\lambda z = 0, \dots (56)$$

$$a_{12}x + (a_{22} - \lambda)y + a_{23}\lambda z = 0, \dots (57)$$

$$a_{13}x + a_{23}y + \frac{1}{\lambda} \lambda z = 0. \dots (58)$$

We notice that there are only two roots in λ for these three equations. Let λ_r ($r=1, 2$) be the roots and let $x_r, y_r, \lambda_r z_r$, be their associated modes. We find by the usual procedure that

$$x_1 x_2 + y_1 y_2 + z_1 z_2 = 0; \dots (59)$$

also we may arrange for

$$x_r^2 + y_r^2 + z_r^2 = 1 (r=1, 2) \dots (60)$$

Here we apparently come to an impasse. But from the third equation, i.e. (58) above, we have

$$a_{13}x_1 + a_{23}y_1 + z_1 = 0, \dots (61)$$

$$a_{13}x_2 + a_{23}y_2 + z_2 = 0. \dots (62)$$

Hence we may regard

$$x_3 = \frac{a_{13}}{\sqrt{A}}, y_3 = \frac{a_{23}}{\sqrt{A}}, z_3 = \frac{1}{\sqrt{A}}, \dots (63)$$

$$\text{where } A = a_{13}^2 + a_{23}^2 + 1 \dots (64)$$

as supplying the deficiency of the third set of rectified modes which set are clearly orthogonal to the other two sets.

The rectified modes just found appear to correspond to an infinite λ root.

We next proceed to consider the fourth-order equations derived by bordering the equations (56), (57), (58), with an additional order such that the bottom right-hand corner term is $\frac{1}{\lambda} \lambda u$ as in equations (75), (76), (77), (78). Then

proceeding from the third- to the fourth-orders we have by the usual artifice

$$(\lambda_r - \lambda)(xx_r + yy_r + zz_r) + (a_{14}x_r + a_{24}y_r + a_{34}\lambda_r z_r)\lambda u = 0, \dots (65)$$

$$\text{or } (\lambda_r - \lambda)[xx_r + yy_r + (z + a_{34}\lambda u)z_r] + p_r \lambda u = 0, \dots (66)$$

$$\text{where } p_r = a_{14}x_r + a_{24}y_r + a_{34}\lambda_r z_r. \dots (67)$$

Thus we have the two equations ($r=1, 2$)

$$xx_r + yy_r + (z + a_{34}\lambda u)z_r = -\frac{p_r}{(\lambda_r - \lambda)} \lambda u \dots (68)$$

and the third equation will be the third of the bordered set, viz.:

$$a_{13}x + a_{23}y + \frac{1}{\lambda} \lambda z + a_{34}\lambda u = 0, \dots (69)$$

which may be written

$$xx_3 + yy_3 + (z + a_{34}\lambda u)z_3 = 0. \dots (70)$$

Now

$$\sum p_r [xx_r + yy_r + (z + a_{34}\lambda u)z_r], \dots (71)$$

where p_1, p_2 , are as given by (67), and

$$p_3 = a_{14}x_3 + a_{24}y_3 + a_{34}\lambda z_3, \dots (72)$$

will be equal to

$$a_{14}x + a_{24}y + a_{34}(z + a_{34}\lambda u)\lambda, \dots (73)$$

which in turn is equal to

$$\left[-\frac{1}{\lambda} + a_{34}^2 \lambda \right] \lambda u. \dots (74)$$

Hence the Escalator equation for the fourth-order equations, viz.:

$$(a_{11} - \lambda)x + a_{12}y + a_{13}\lambda z + a_{14}\lambda u = 0, \dots (75)$$

$$a_{12}x + (a_{22} - \lambda)y + a_{23}\lambda z + a_{24}\lambda u = 0, \dots (76)$$

$$a_{13}x + a_{23}y + \frac{1}{\lambda} \lambda z + a_{34}\lambda u = 0, \dots (77)$$

$$a_{14}x + a_{24}y + a_{34}\lambda z + \frac{1}{\lambda} \lambda u = 0; \dots (78)$$

will be

$$\sum_1^3 \frac{p_r^2}{(\lambda_r - \lambda)} = \frac{1}{\lambda} - a_{34}^2 \lambda. \dots (79)$$

It may be noticed that this equation will now have four roots. For subsequent stages the process presents no unusual features.

Acknowledgment

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VISCOUS EFFECTS IN COMPRESSIBLE FLUIDS

It is regretted that, owing to no price being mentioned in it, it was assumed that the report on the theory of compressible fluids summarized on p. 83 of the March issue of AIRCRAFT ENGINEERING was issued free by the Durand Reprinting Committee; whereas, we are now informed, a charge is made for it of 2 dollars, plus 18 cents postage overseas.

HELICOPTER AIRFLOW PATTERNS

It is regretted that in the article with the above title on p. 109 of the April issue Figs. 10 and 11 were transposed.

Failure of Cylindrical Tubes Under External Pressure

The Various Types of Failure Considered and Suitable Formulae for Each Case Developed

By R. C. C. Ringrose

UNDER external pressure cylinders fail in the following ways:

Pure tension, compression (due to hoop and radial stresses).

Flexural instability (Euler buckling).

Elastic instability (buckling of the shell of the cylinder).

1a. Thick cylinders

If the walls of the cylinder are relatively thick compared with its radius (wall thickness greater than 1/10R), under external pressures hoop and radial stresses are induced in the walls.

These can be determined by Lami's method and give:

$$S_1 = \frac{1}{r_2^2 - r_1^2} \left[p_2 r_2^2 - p_1 r_1^2 + \frac{(p_1 - p_2) r_1^2 r_2^2}{r^2} \right]$$

$$S_2 = \frac{1}{r_2^2 - r_1^2} \left[p_1 r_1^2 - p_2 r_2^2 + \frac{(p_1 - p_2) r_1^2 r_2^2}{r^2} \right]$$

r_1 = internal radius p_1 = internal pressure
 r_2 = external radius p_2 = external pressure
 s_2 = hoop stress s_1 = radial compressive stress

1b. Semi-thick cylinders

A moderately thick cylinder may collapse under external pressure at stresses above the proportional limit, but below the yield point. This is similar to the failure of a short strut.

Then the collapsing pressure is given by

$$p = \frac{t}{r} \left[\frac{S_y}{1 + 4 \frac{S_y}{E} \left(\frac{r}{t} \right)^2} \right]$$

S_y = compressive yield point

This formula holds only when $\frac{pr}{t} >$ proportional limit.

1c. Thin cylinders

In thin cylinders there is no radial stress, and they can fail under a hoop compressive stress of $\frac{pr}{t}$. Failure however is much more likely to occur due to instability (flexural and elastic).

2. Flexural instability

Failure due to flexural instability is analogous to the buckling of a long strut (Euler effect) under compressive loading, i.e. the walls of the cylinder flex.

The formula for this (due to Föppl) is

$$p = \frac{3EI}{r^3}$$

I = Moment of inertia of cross section of the cylinder wall.

p = failing load per inch run across the wall

3. Elastic instability

Failure here is due to local buckling of the skin when the walls are very thin and it is from flat plate theory that the following formulae are obtained.

REFERENCES TO LITERATURE
 Timoshenko. *Theory of Elastic Stability*. McGraw Hill. 1936.
 R. V. Southwell. *Phil. Trans. Roy. Soc.* 1913.
 H. E. Saunders and D. F. Windenburg. *Trans. Am. Soc. Mech. Eng.*, Vol. 53, No. 15. 1931.
 Roark. *Formulas for Stress and Strain*. McGraw Hill.

Notation

r = mean radius of the cylinder.
 t = wall thickness.
 l = length of tube.
 E = Young's Modulus for the material.
 ν = Poisson's ratio.

TABLE I—SUMMARY OF STRESSING CASES

Case	Type of Stress or failure	Formula
1. Thick cylinder	Radial and hoop stresses	$S_1 = \frac{1}{r_2^2 - r_1^2} \left[p_2 r_2^2 - p_1 r_1^2 + \frac{(p_1 - p_2) r_1^2 r_2^2}{r^2} \right]$ $S_2 = \frac{1}{r_2^2 - r_1^2} \left[p_1 r_1^2 - p_2 r_2^2 + \frac{(p_1 - p_2) r_1^2 r_2^2}{r^2} \right]$
2. Semi-thick cylinder	Compressive hoop stress	$p = \frac{t}{r} \left[\frac{S_y}{1 + 4 \frac{S_y}{E} \left(\frac{r}{t} \right)^2} \right]$
3. Thin cylinder (a)	Compressive hoop stress	$S_2 = \frac{pr}{t}$
(b)	Buckling	$p = \frac{3EI}{r^3 l}$
(c) Long tube	Skin instability	$p = \frac{1}{4} \frac{E}{1 - \nu^2} \frac{t^3}{r^3}$
(d) Short tube length l	Skin instability	$p = 0.807 \frac{Et^2}{lr} \sqrt[4]{\frac{1}{(1 - \nu^2)^3} \times \frac{t^2}{r^2}}$
(e) With closed ends	Skin instability	$p = \frac{E \left(\frac{t}{r} \right)}{1 + \frac{1}{2} \left(\frac{\pi r}{nl} \right)^2} \left[\frac{1}{n^2 \left\{ 1 + \left(\frac{nl}{\pi r} \right)^2 \right\}^2} + \frac{n^2 t^2}{12r^2(1 - \nu^2)} \left\{ 1 + \left(\frac{\pi r}{nl} \right)^2 \right\} \right]$
(f) Curved panels subtending angle 2α at centre	Skin instability	(1) Straight edges hinged $p = \frac{Et^3 \left(\frac{\pi^2}{\alpha^2} - 1 \right)}{12r^3(1 - \nu^2)}$ (2) Straight edges clamped $p = \frac{Et^3 (K^2 - 1)}{12r^3(1 - \nu^2)}$ [$K \tan \alpha \cot K\alpha = 1$]

The failing pressure of a short, thin tube depends upon (among other things) the length. As the magnitude of the length increases the failing pressure decreases proportionately until a value is reached above which the failing pressure is independent of the length.

This value 'l' is known as the critical length and is given by the formula

$$l = 4.9r \sqrt{\frac{r}{t}}$$

This applies only for steel tubes and has been determined by experiment.

Thus to find the failing pressure of a thin tube, determine its critical length.

If this is less than the length of the tube use formula in (I)

If greater use formula in (II).

Formulae for the failure of thin tubes and cylinders

(i) Very long tube of length 'l'

$$p = \frac{1}{4} \frac{E}{1 - \nu^2} \frac{t^3}{r^3} \text{ for } l > 4.9r \sqrt{\frac{r}{t}}$$

(ii) Short tube of length 'l'

This formula also applies to a long tube constrained at intervals of length 'l'. The ends are assumed to be held circular. The failing pressure p is given by

$$p = 0.807 \frac{Et^2}{lr} \sqrt[4]{\frac{1}{(1 - \nu^2)^3} \times \frac{t^2}{r^2}}$$

(iii) Thin tubes with closed ends

The external pressure here is both lateral and longitudinal, and the ends are assumed to remain circular. Failure occurs when the skin breaks up into lobes and the failing pressure is given by

$$p = \frac{E \left(\frac{t}{r} \right)}{1 + \frac{1}{2} \left(\frac{\pi r}{nl} \right)^2} \left[\frac{1}{n^2 \left\{ 1 + \left(\frac{nl}{\pi r} \right)^2 \right\}^2} + \frac{n^2 t^2}{12r^2(1 - \nu^2)} \left\{ 1 + \left(\frac{\pi r}{nl} \right)^2 \right\} \right]$$

where n is the no. of lobes formed in the tube by buckling.

To find min. p : plot p against $\frac{l}{r}$ for integral values of $n > 2$. Then min value of p for the given $\frac{l}{r}$ in this group of curves is the required value.

(iv) Curved panel under uniform radial pressure

For a curved panel of radius of curvature 'r' subtending angle 2α at the centre the failing pressure is given by

(a) Straight edges hinged (curved edges free)

$$p = \frac{Et^3 \left(\frac{\pi^2}{\alpha^2} - 1 \right)}{12r^3(1 - \nu^2)}$$

(b) Straight edges clamped (curved edges free)

$$p = \frac{Et^3 (K^2 - 1)}{12r^3(1 - \nu^2)}$$

where K is defined by the equation
 $K \tan \alpha \cot K\alpha = 1$.

Note

- When stress checking a thin cylinder, the cylinder should be capable of satisfying all the thin cylinder cases.
- For long cylinders, reinforced at intervals of length 'l' by frames, it has been found by experiment that the strength of the frames should be at least 10 per cent stronger than the shell lying between the frames assuming both cylinder and frame to fail under buckling i.e. using Föppl's equation:

$$\text{Thus } 1.1 \left(\frac{3EI}{r^3 l} \right)_c = \left(\frac{3EI}{r^3 l} \right)_s$$

where suffices c, s denote cylinder and frames respectively.

Flight Characteristics at High Mach Numbers

A paper presented by V. Outman and G. V. Graff* at the High Speed Flight Symposium of the IAS-SAE at New York City on March 16, 1950

Introduction

DEVELOPMENT test flying of a prototype aeroplane is playing an ever-increasing role of importance in the ultimate design of high performance military aircraft. When a prototype aircraft is rolled out of the Experimental Shop and made ready for its initial test flight, it is far from being a finished product. The first flights invariably reveal numerous shortcomings in the aeroplane's performance, stability, control, and handling characteristics, many of which are of a limiting nature. That is to say they are sufficiently serious to prevent the pilot from achieving the estimated design performance of the aeroplane. The many months of intensive design effort on the part of engineers and shop personnel have set the stage for an all-out development, modification, and flight test programme which frequently taxes their ingenuity and energy to a far greater degree than did the initial design work.

This discussion is concerned with such a development programme on one particular type aeroplane and on one particular flight characteristic, the flying qualities at high subsonic Mach numbers. Some pilots refer to an aeroplane with disturbances at high Mach numbers as 'having the Machs'. Sometimes the Machs occur in one part of the aeroplane and sometimes in another. As improvements are made the Machs disappear from one part of the aeroplane and appear in another part. Most of the modifications were of little value; however enough were successful to make a considerable gain between the first prototype version and the production aeroplane.

General

The achievement of satisfactory aeroplane flight characteristics at high subsonic Mach numbers represents a relatively new field of endeavour for the aeronautical engineer. Consequently, there has been a great deal of improvising in both the development and flight test techniques, as is evidenced by the illustrations of the various modifications attempted during this programme. In general, relatively large gains

were made from minor modifications at the start of the programme when the limiting condition occurred at low Mach number. However, as the limiting Mach number approached the design speed of the aeroplane more drastic changes were required to achieve even a small gain.

The limitations to satisfactory high Mach number characteristics on this aeroplane can be conveniently grouped into four major categories. Those involving instability or roughness of the three principal control surfaces; ailerons, rudder and elevator; and those involving motion of the entire airframe.

Early Flights

Early in the programme a limiting shake of the entire airframe was encountered. Airframe shake was defined as that roughness which the pilot feels in the seat as a motion of the entire airframe, in contra-distinction to the roughness or oscillation of any particular control surface which is felt through the control stick or rudder pedals. It must be admitted that airframe roughness so defined could be caused by control surface roughness or vice versa. Indeed, it was extremely difficult throughout the programme to separate the two phenomena; so much so that there is still considerable difference of opinion as to what was shaking what and why. By flying the aeroplane at various altitudes up to the speed beyond which the pilot considered it unsafe to fly, the trouble was determined to be a compressibility phenomena and not one due to indicated airspeed.

In an effort to discover what part of the airframe was causing the trouble, tufts of regular knitting yarn were fastened with scotch tape to the wing and tail surfaces. Photographs of the tufts in flight were made by the pilot of the chase plane by means of a hand-held camera or by a camera mounted in the fuselage and operated remotely by the pilot. It was not exactly necessary to have a record taken during flight because some indication could be obtained by observing the tufts which blew off during flight. The region of disturbed flow was clearly indicated by the absence of tufts.

The most critical section was at the root of the

wing and the intersection of the horizontal and vertical tail, primarily on the upper surface. In order to improve these conditions a number of modifications were made. The trailing-edge angle at the wing root was very large and to obtain better flow conditions the trailing-edge angle was reduced considerably by a fairing. Another change was a dorsal fin. The idea here was to reduce the thickness ratio of the vertical tail and to move the peak pressure on the horizontal tail away from that on the vertical tail. Changes were also made to the leading edge by applying a fillet. Observations made from a chase aeroplane showed the flow from the side of the fuselage to sweep up near the end of the aeroplane. To improve this condition a so-called 'spray strip' was put on the fuselage to try to keep the flow straight. The flow from the canopy was suspected, so tufts were mounted to indicate any disturbance that might be coming from the canopy and hitting the tail. A lagging or anti-balance tab ratio was used on the elevator. A trailing edge fillet mounted on the horizontal tail and fairing back on to the rudder was applied. It was recognized that 15 degrees dihedral in the horizontal tail made the condition at the intersection more critical, therefore it was reduced as much as the particular structure permitted. After making all these changes the rudder roughness was still a limiting factor but at a Mach number 20 per cent higher than for the configuration first flown. FIG. 1 shows the configuration of the aeroplane as it was first flown and FIG. 2 shows it after the changes mentioned above.

Effect of other Modifications

These changes, however, had another more significant effect. Instead of being limited by rudder roughness the aeroplane encountered aileron difficulties. High frequency, single degree of freedom oscillations of the ailerons, popularly called 'buzz', have been encountered on several other high speed aircraft. The roughness encountered on this aeroplane seldom exhibited the harmonic characteristics of the 'buzz' phenomena, but manifested itself instead as an irregular roughness of the aileron controls with a tendency toward lateral instability and wing heaviness. At times the various conditions would occur at different altitudes on the same flight. To cure this phenomenon the seal balance was ventilated. Rigging the ailerons up or down was tried. It was concluded that more damping was needed. A friction damper was constructed which required 6 lb. on the top of the control stick to move the aileron. This was all the pilot would put up with. A hydraulic damper was designed and installed.

The design of an aileron power boost system had been started to obtain lower aileron forces, so it was installed and tested. After improving this condition the Machs were chased out of the wing but they reappeared in the airframe and

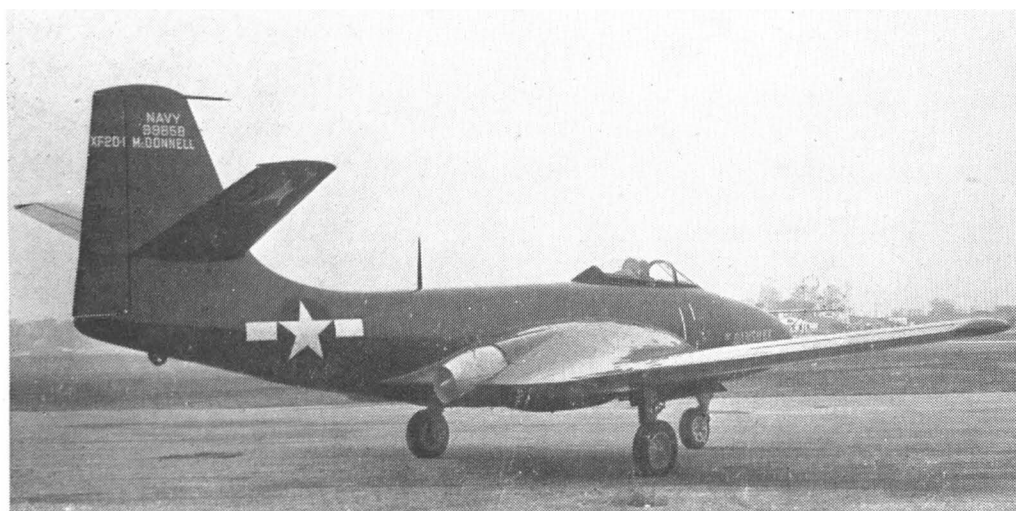


Fig. 1.—First flight tail of the McDonnell Banshee

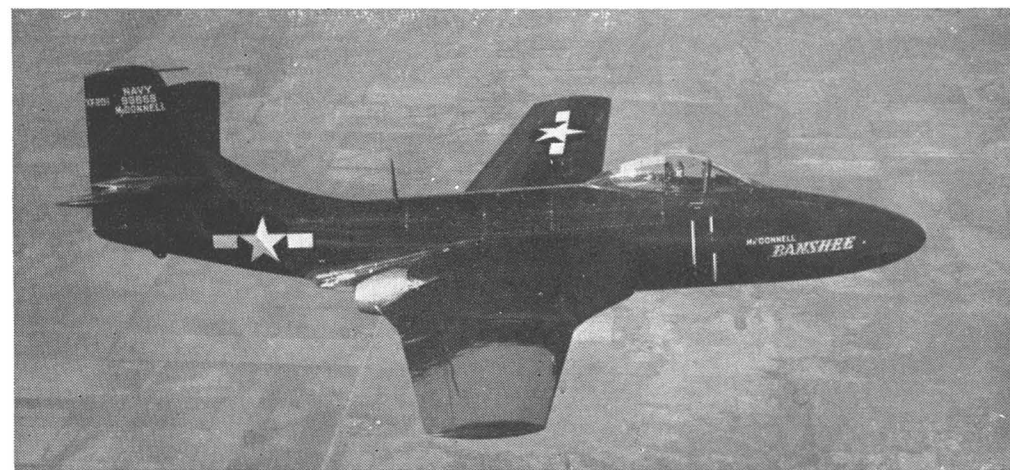


Fig. 2.—The Banshee after the first changes to the tail unit

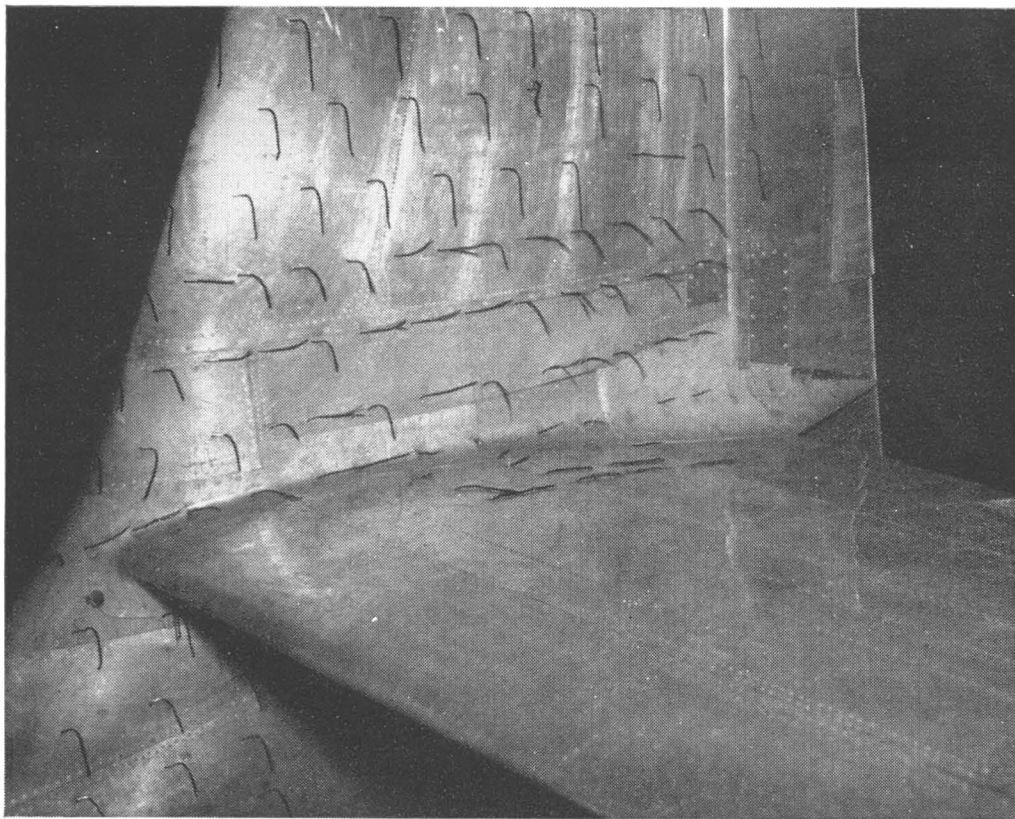


Fig. 3.—First wool tuft tests on the fin

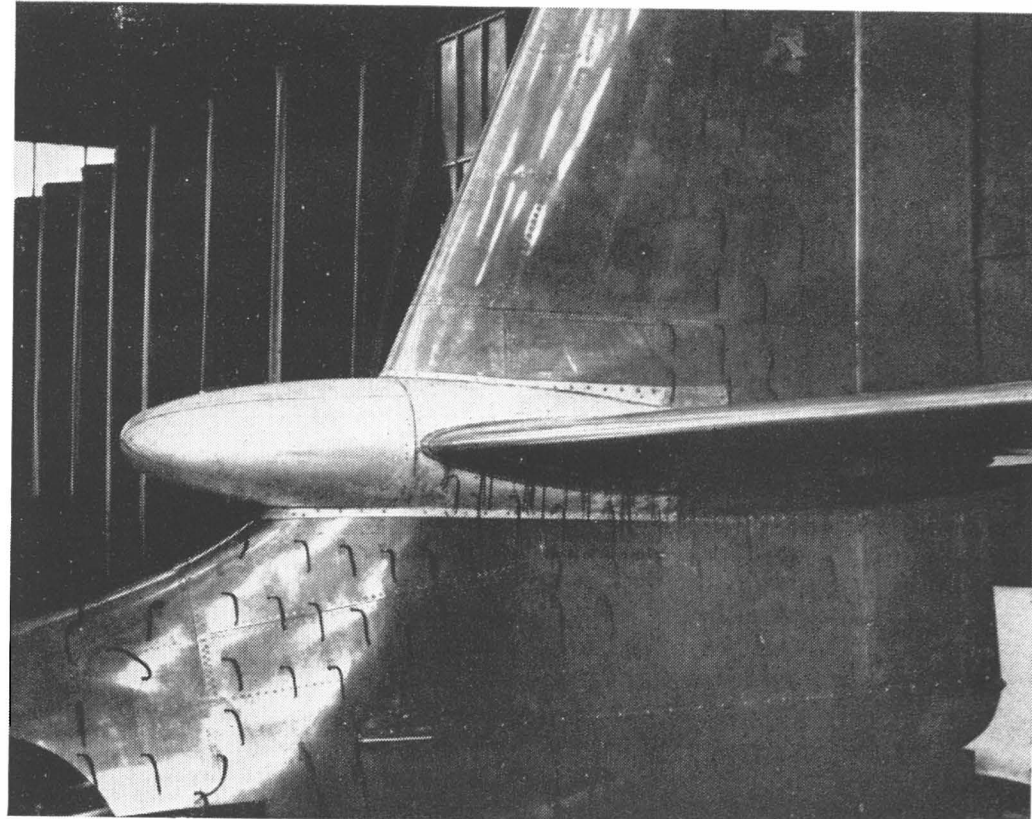


Fig. 4.—A bullet fairing tried on the fin tail plane junction



Fig. 5.—A tail fairing added to the bullet



Fig. 6.—The addition of a very large fillet to the bullet fairing

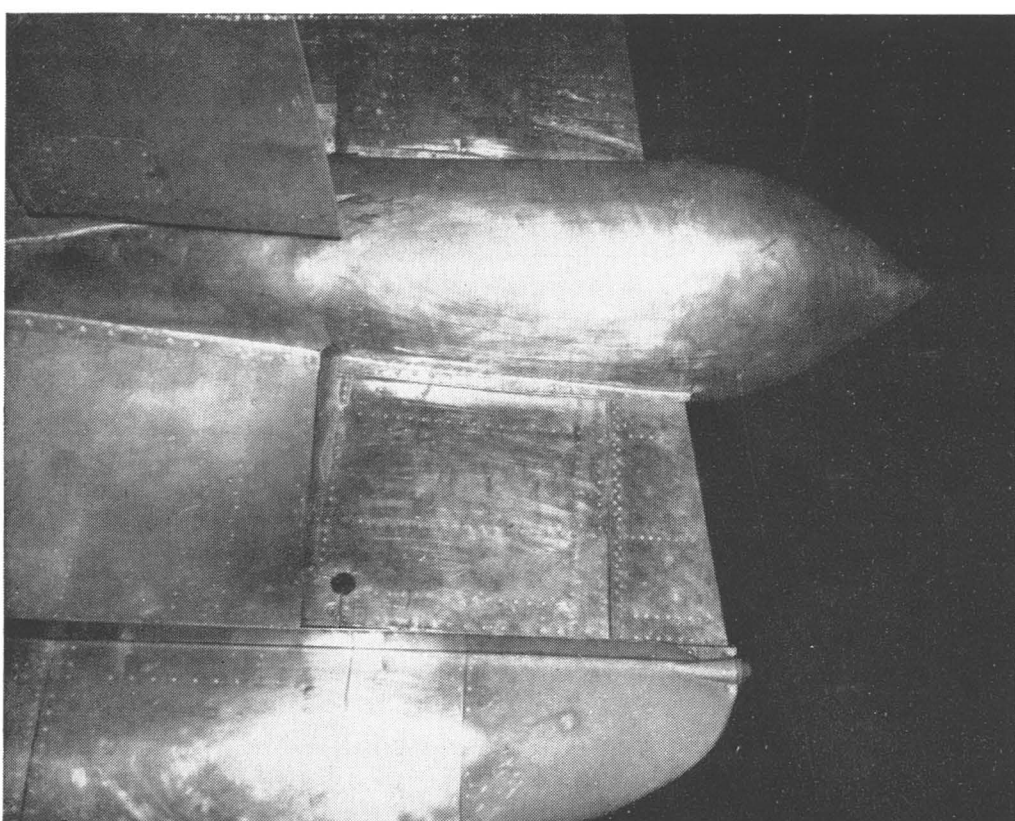


Fig. 7.—A very large tail bullet used to induce three-dimensional flow

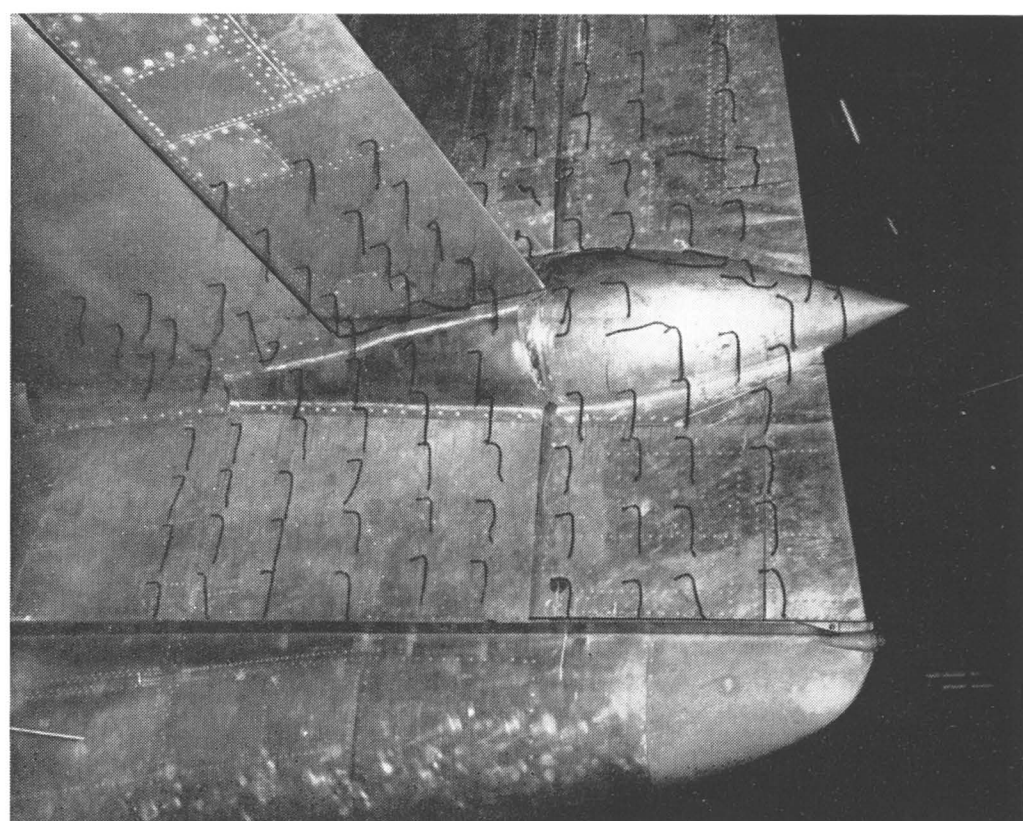


Fig. 8.—A variant of the large tail bullet for three-dimensional flow

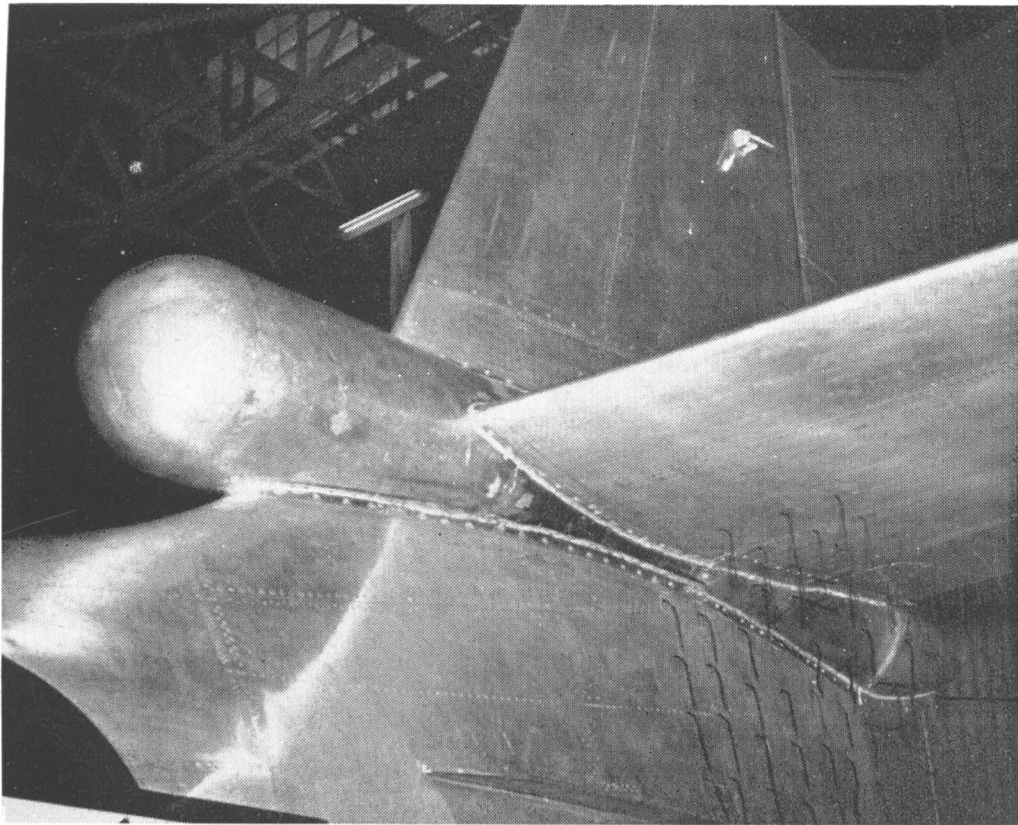


Fig. 9.—A curious blunt nose bullet fairing

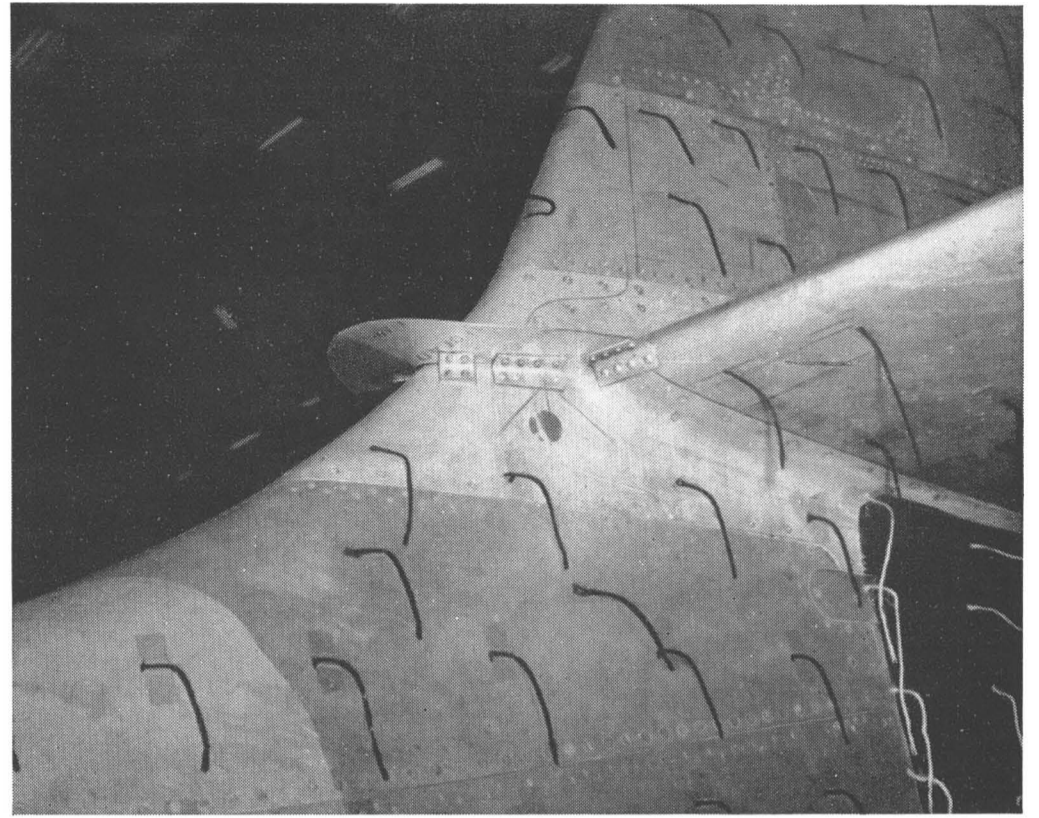


Fig. 10.—A horizontal separator plate intended to check up-flow

rudder. Airframe shake and rudder buffeting were again the limiting factors. Also at this point tuck-up was encountered. This is a phenomenon in which the aeroplane does not want to dive steeper in spite of the pilot using full strength to push the stick forward and rolling in full down trim tab.

An all-out programme then got under way to improve rudder roughness and airframe shake. FIG. 4 shows a bullet fairing which was applied. This was tried with and without a tail fairing as shown in FIG. 5. The 'grand-daddy' of all tail fillets was installed as shown in FIG. 6. In an attempt to get three-dimensional flow a very large bullet was installed. This is shown in FIG. 7 and another version in FIG. 8. A variation of the nose shape was tried as shown in FIG. 9.

Because of the large amount of up flow in the region of the horizontal tail, a horizontal separation plate was attached. The idea was to prevent the up flow and perhaps avoid separation on the upper surface of the horizontal tail. This is shown in FIG. 10.

Thinking that combinations might be helpful, an attempt was made to combine both the bullet and the horizontal separation plate. FIG. 11 shows

this combination. We then applied the horizontal separation plate to the dorsal fin as shown in FIG. 12.

On all of these modifications we had been recording the accelerations in the tail versus Mach number. FIG. 13 shows the variation in 'g' at the tip of the stabilizer versus Mach number. The vibrations in an early version are compared with one of the later configurations.

It had been previously concluded as a result of the tuft studies at high Mach numbers that the wing and tail surfaces should be thinner. This was accomplished by building a new outer panel and modifying the trailing edge of the inner wing. In making this change it was also possible to reduce the horizontal tail dihedral to zero degrees.

With these wings and tail surfaces other modifications were tried. Carrying the horizontal separation plate idea still further, the modification in FIG. 14 was tried. Not having been completely sold on the uselessness of a fillet, another was tried on the aeroplane in this configuration. In addition we went full out on the idea of using spray strips to keep the flow from sweeping upward. FIG. 15 shows one of the most drastic configurations.

All the phenomena discussed above are a function of the Mach number. Even though the reaction experienced by the pilot is different and the disturbing flow occurs on different parts of the aeroplane there is still one basic cause. As the Mach number is increased the pressure distribution on various parts of the aeroplane changes so that the pressure gradient on the aft portion of the body increases. When a critical gradient is reached separation occurs. This separation creates roughness which is transmitted through the aeroplane to the pilot. It is sometimes transmitted through the airframe itself and at other times when the separation occurs on a control surface it is transmitted through the controls. This accounts for the various types of roughness or shaking experienced by the pilot.

As Mach number increases the change in pressure distribution, both before and after separation occurs, also changes the forces and moments exerted on the aeroplane. This can be an unsteady condition in which the aeroplane is oscillated about any one of the three axes. On the other hand it can also be a steady flight condition at a given Mach number in which the trim of the aeroplane changes. This re-trimming condition

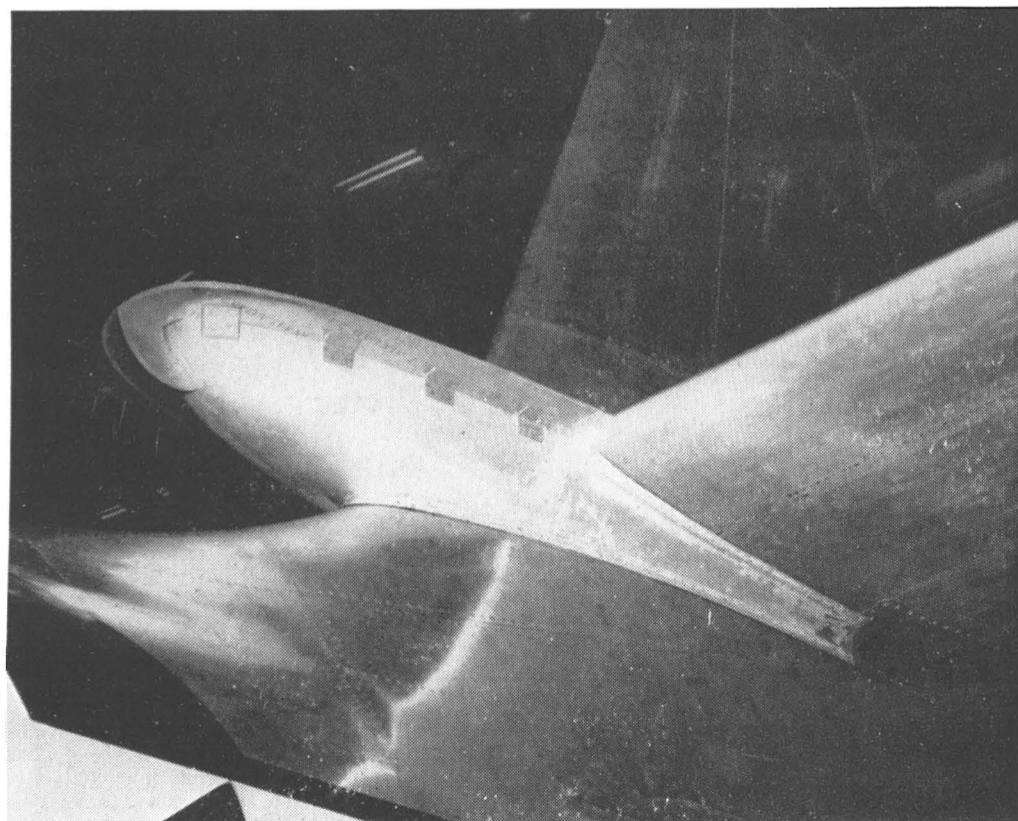


Fig. 11.—A combination of the bullet nose fairing and the separator plate

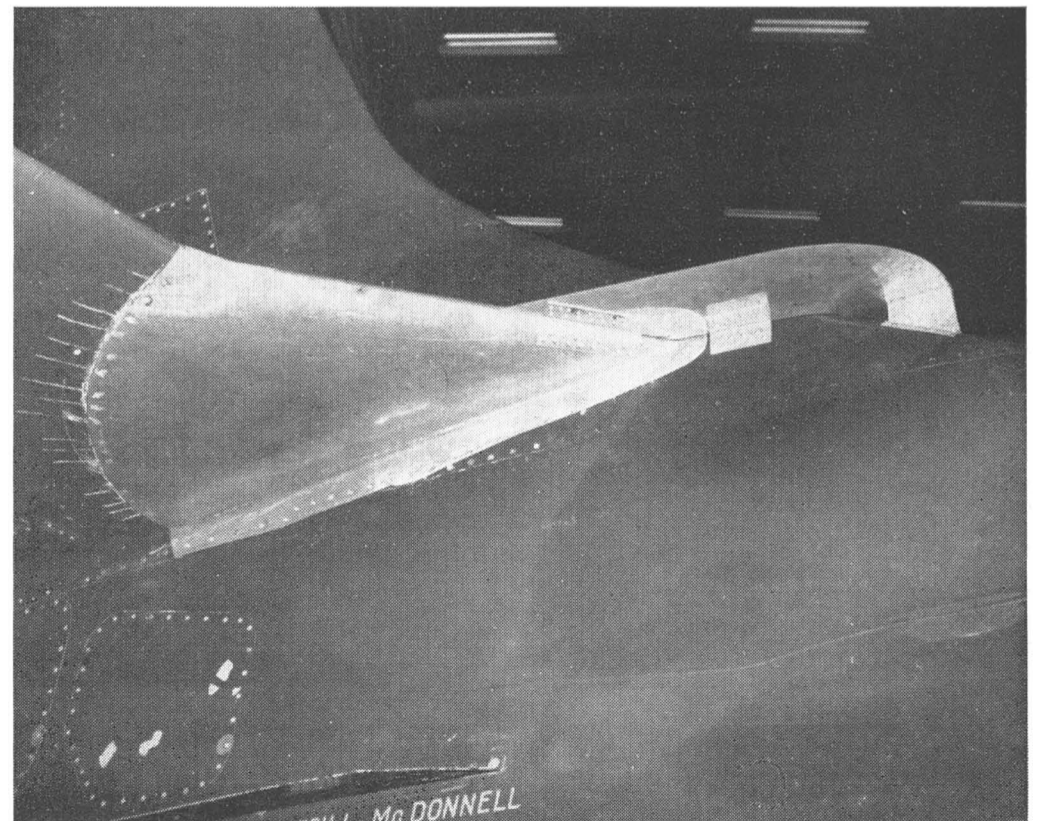


Fig. 12.—An extension of the tail plane combined with a separator on the fin

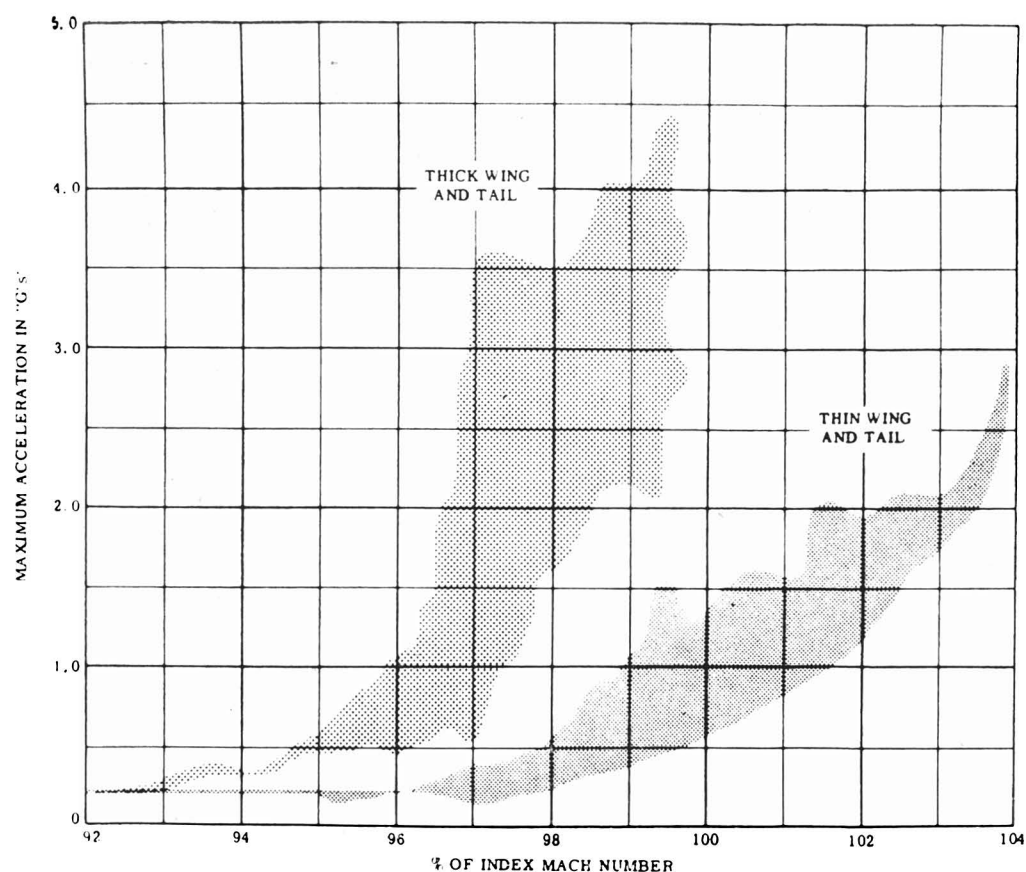


Fig. 13.—Variation of maximum acceleration (in g s) at horizontal tail tip with Mach number

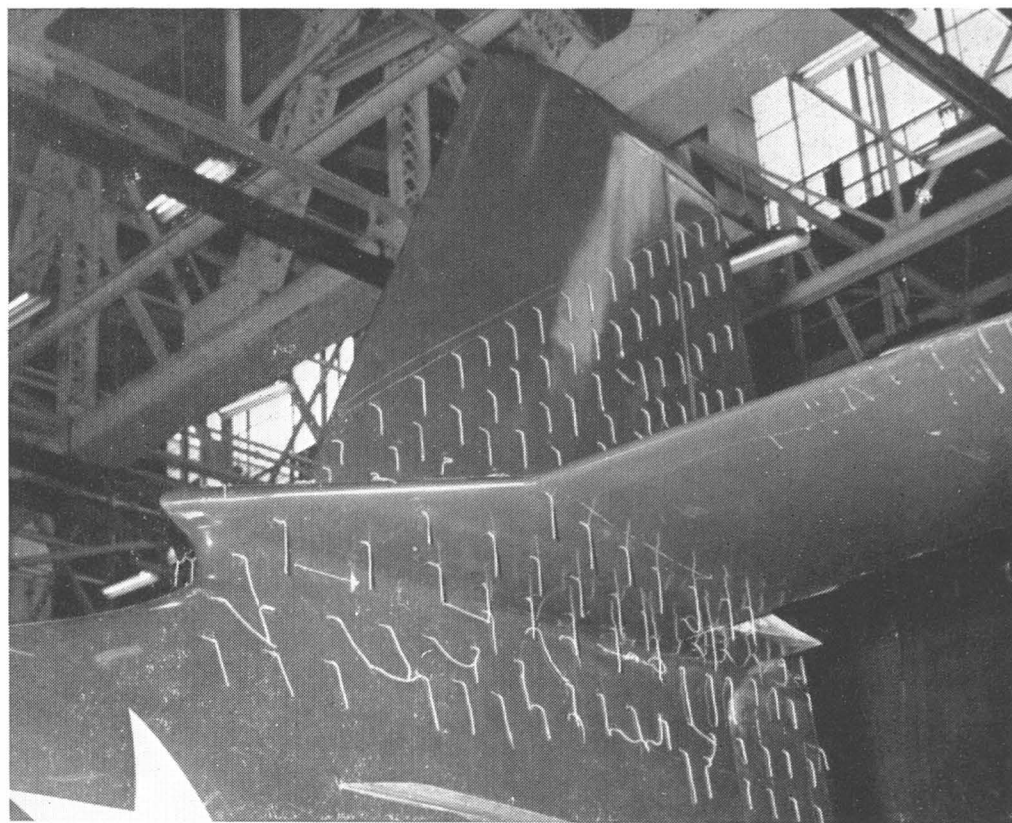


Fig. 14.—An extended horizontal separator strip

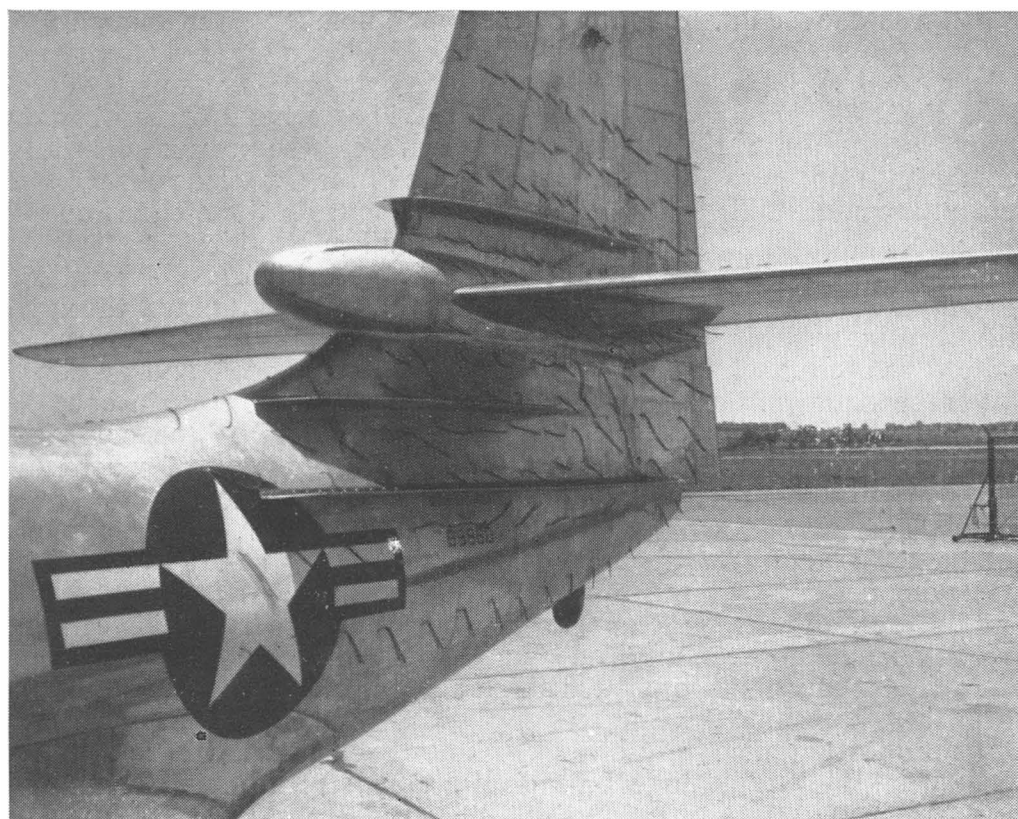


Fig. 15 (left).—Bullet fairing and air-flow strakes

Fig. 16 (right).—The simple tail finally adopted

can exist as a result of the change in the basic moments exerted on the aeroplane or the change in hinge moments or control surface effectiveness which may be altered due to the variation in pressure distribution and separation. Thus no matter what form of disturbance occurs and is reported by the pilot and no matter what part of the aeroplane causes the trouble, the basic change is due to these compressibility effects.

By determining which part of the aeroplane first experiences some type of Mach number effect and modifying it so that this no longer occurs, considerable improvement can be obtained. At the end of this programme, airframe shake and rudder roughness were still present. The tuck-up tendency was still present, but to a degree which was not dangerous. It was more of a

safety feature in that it prevented the pilot from getting into other troubles. The production aeroplane with the best of the modifications previously described experienced Mach number effects at a speed 30 per cent higher than when the aeroplane was first flown. FIG. 16 shows the aeroplane in the final configuration and can be compared with the aeroplane as initially flown.

Conclusions

As a result of the flight test development programme conducted on this aeroplane several conclusions can be drawn.

First, it is possible by a series of modifications to affect a relatively large increase in the limiting Mach number of a new aeroplane. In the case of this aeroplane the best of the modifications

described in this paper resulted in almost 30 per cent increase in limiting Mach number.

Secondly, with specific reference to the high Mach number characteristic, there is a definite need for the development of satisfactory instrumentation and flight test technique. The use of tufts is not a wholly satisfactory method of locating the cause of roughness or separation. It generally requires the use of a chase aeroplane of comparable performance, which in the case of a new design is not always available. The use of accelerometers in conjunction with an oscillograph gives a good quantitative measure of the roughness at any point on the airframe but no indication of the source of the roughness. This technique was used extensively throughout this programme to evaluate the effect of various modifications on the roughness and shake of any part of the aeroplane but was of little use in locating the source of trouble.

Lastly, the importance of development flight testing is rapidly increasing. The ever-present demand for increased performance will always result in new designs flying at previously unexplored speeds and altitudes. Moreover, the increasing complexity of modern military aircraft will necessitate more extensive flight testing to 'de-bug' the maze of electronic, hydraulic, and mechanical gear they are compelled to carry.

Servicing Aircraft Wheels, Brakes and Tyres

Goodyear Aircraft Service Manual
[The Goodyear Tyre and Rubber Co. (Gt. Britain) Ltd., Wolverhampton.]

This quarto looseleaf book presents, in ample detail, descriptions, together with full servicing instructions, concerning the Goodyear range of

aircraft tyres and tubes, their cross-wind landing gear and their wheel and brake equipment—including the single-disk brake. One imagines that the brochure is a reprint of the material required for official handbooks on the equipment, and very excellent it is, both as regards text and illustrations. It is the sort of booklet that all Licensed Aircraft Engineers would wish to possess.

The Estimation of Wing Weight*

A Method of Predicting Structural Weight by Relating the Design to an Ideal Wing

By J. Solvey

Summary

This paper suggests a means of estimating wing weight using formulae based on the theoretical ideal wing.

The predicted wing weight is attained by multiplying the weight of the ideal wing by a correction factor derived from a statistical analysis of actual wing weights.

The method has the advantage that it provides the designer with a yardstick by which to compare alternative designs and indicates where improvement might be effected.

1. Introduction

THE estimation of wing weight has always been a very important problem in aircraft design. Its importance is twofold: firstly—the wing weight is part of the total weight of the aircraft, whose value is needed to calculate performance and balancing. Secondly, the wing weight relieves the air loading on the wing. Therefore the precise knowledge of wing weight is of great importance in wing design.

2. Existing Methods

The prediction of the structural weight of the wing (as distinct from the total weight, i.e. including such items as the engines with nacelles, controls, armament, etc.) was, until comparatively recently, based on average values. The method was rather simple. The wing structural weight, as obtained from actual weighings, was plotted against some parameter (W or $2s$), or against a combination of parameters ($N\frac{W}{S}2s$, etc.) and a reasonable average curve or curves (as functions of some other parameter, say, $A.R.$) was drawn.

Several formulae¹ derived from these data are as follows:

$$W_w = 5340 \left(\frac{2s}{100}\right)^3 \dots\dots\dots (1)$$

$$W_w = 0.114W \dots\dots\dots (2)$$

$$W_w = 0.000212WN(2s+33) \dots\dots\dots (3)$$

Formulae 1 to 3 can be represented by one curve.

Another formula of this type is:

$$\frac{W_w}{S} = (k_1 + k_2 A.R.) N 2s \frac{W}{S} + k_3 \dots\dots\dots (4)$$

where k_1 , k_2 , k_3 are numerical coefficients expressed in length⁻¹, length⁻¹ and weight/length², respectively.

Formula 4 is valid for metal aircraft only.

Plotting $\frac{W_w}{S}$ (unit wing weight) against $N 2s \frac{W}{S}$, a family of straight lines, for fixed $A.R.$ values, is obtained.

All these formulae, regardless of their degree of accuracy, suffer from several disadvantages. They are all averages of achieved results which do not indicate whether the design has been well executed or not. They do not indicate the possible improvements, nor do they enable the comparison of the relative merits of various design alternatives such as, type of structure, choice of material,

Notation

All formulae

W — lb. All-up weight of aircraft

W_w — lb. Weight of wing (structural)

S — sq. ft. Wing area

$2s$ — ft. Wing span

N — — Ultimate design factor

$A.R.$ — Aspect ratio = $\frac{(2s)^2}{S}$

Formulae 1 to 5

$$r = 1 - \frac{W_1}{W}$$

W_1 — lb. Effective relief weight³

c — ft. Wing chord at root

t — ft. Wing thickness at root

ϕ — Rad. angle of sweepback

V_D — f.p.s. Design diving speed of the aircraft

Formulae 6 to 14

a — ft. Distance from tip to mid-aileron (spanwise)

c — ft. Wing chord (see subscripts)

d — ft. Wing depth (see subscripts)

f — p.s.f. Allowable stress (see subscripts)

G — p.s.f. Shear modulus of skin

g — Wing section perimeter parameter
Perimeter = $2(c+gd)$

g_t — Same for torsion box only
Perimeter of torsion box = $2(c+g_t d)$

h — Wing section area parameter
Section area = hcd

h_t — Same for torsion box
Area of torsion box = $h_t c d$

$m = \frac{d_r - d_t}{s}$ Wing depth taper ratio

m_0 lb.ft./rad. Mid-aileron torsional stiffness (required)

$n = \frac{c_r - c_t}{s}$ Wing chord taper ratio

P_i — lb. Concentrated load in the wing

x_i — ft. Distance of the point of application of load P_i from the tip

δ — lb./ft.³ Density of material

ψ — Coefficient⁴

Subscripts—geometric

a — mid-aileron

r — root

t — tip

Subscripts—stresses

c — compression

s — shear

t — tension

Subscripts—material

f — flange

sw — spar web

s — skin

etc. All they tell is whether the actually achieved weight is higher or lower than the average so far achieved; they give no indication of where the improvement can be effected.

REFERENCES TO LITERATURE

(1) J. F. Carreyette. Aircraft Wing Weight Estimation. AIRCRAFT ENGINEERING, Vol. XXII, No. 251, January 1950.

(2) B. Göthert. Einfluss von Flächenbelastung, Flügelstreckung und Spannweitenbelastung auf die Flugleistungen. *Luftfahrtforschung*. Band 16, Lfg. 5, pp. 219-282, 20-5-1939.

(3) F. Grinsted. Simple formulae for predicting the weights of wing, fuselage and tail unit structures. RAE Report Structures 24, May 1948.

(4) J. Solvey. Structural Efficiency of Wings. ARCC Report, ACA-44, March 1949.

The next step in wing weight prediction was the derivation of formulae of a semi-empirical nature. These formulae take into account the influence of the various parameters on the weight of wing components. Adjusting these separate items of the wing weight with the help of statistically established coefficients, formulae for wing weight prediction are obtained.

A formula of this type suggested by Grinsted³ is:

$$\frac{W_w}{W} \cdot \frac{100}{K} = N 2s r \left[\frac{0.0003(2s)^2 \sec^2 \phi}{S(t/c)} + 0.007 \sec \phi + 0.0015 \right] + \frac{16S^2(t/c)}{2sW} + \frac{8V_D^2(2s)^3}{10^9 W(t/c)^2} + \frac{90S}{W} + Q \dots\dots (5)$$

where K is a coefficient depending on the taper, and Q is a constant.

Theoretically, Formula 5 is an advance in this field but suffers, nevertheless, from the shortcomings of the previous formulae.

As to the practical accuracy of Formula 5 and other similar ones, Ref. 1 seems to indicate that they do not represent any improvements on Formulae 1 and 2. This statement of Ref. 1, however, should be accepted with reserve, since the calculation of deviations allows plenty of room for individual interpretation.

3. New Approach

This state of affairs, no matter how unsatisfactory it might have been, was dictated by the very nature of aircraft design. The rapid progress of structural design has precluded any other methods. Today, however, the situation has changed as far as the subsonic aircraft is concerned—and the latter will still be of importance for some time—since, in aircraft of this class, structural design has achieved a certain degree of uniformity.

In view of the above, it seems that the present time is opportune to review the methods of predicting wing weight. A stage has been reached where this estimate can be dealt with in the logical way, namely—the establishment of the minimum theoretical weight of the wing, with correcting factors, which may be altered from time to time to obtain the actual wing weight.

Once the theoretical wing weight has been established, the ratio of the actual to the theoretical weight—always greater than one—will provide the correction factor (or efficiency coefficient).

By applying statistical analysis methods to these correction factors, average numerical values of the latter can be obtained. They will have to be grouped according to operational requirements; size, number of engines or other relevant features. There is, of course, little likelihood of all types having the same average values. These factors need not remain constant as in existing formulae. They can be progressively adjusted as better and more efficient types of construction and of stressing methods are introduced.

Should the numerical investigation require it, the method can be extended to the main wing components (skin, spar flanges and stringers, spar web and ribs) individually. That is, actual and theoretical weights compared and numerical correction factors obtained.

* Structures and Materials Tech. Memo. 26, 'On Aircraft Wing Weight Estimation', issued by the Department of Supply, Aeronautical Research Laboratories, Melbourne, Australia.

This approach has a triple advantage.

1. Knowing the minimum theoretical weight (which, of course, can never be achieved), the designer can easily judge what weight saving, if any, can be expected. His judgment will be based on objective values, not on achieved averages.
2. The designer is provided with a yardstick by which to compare alternative designs from the point of view of structural efficiency. This eliminates the need for laborious calculations of the wing weight from drawings and, what is more important, provides a guide in the beginning and not at the end of the design and stressing work.
3. Comparing the correcting factors of various completed (and built) projects, one can immediately judge the efficiency of execution (detail design, stress analysis and manufacture). A high ratio of actual over theoretical weight generally indicates a low standard of detail design and stress analysis.

4. Suggested Formula

A formula of the above-mentioned type, that is, showing the minimum theoretical structural weight of a wing, based on earlier work of Roxbee-Cox, has been developed by the author.⁴

The formula is based on two main design requirements:

- A. Prescribed direct stresses in spar flanges (including stringers and skin) and shear stresses in spar webs, all constant spanwise.
- B. Prescribed torsional stiffness of the wing.

The formula given below is not the 'complete' formula of Ref. 4. It has been considerably simplified as a result of numerical investigations, see Ref. 4.

$$r_i'' = \frac{W_w}{W} = \frac{E+J_e}{H} + \frac{2t^* K}{W} - \Delta s - \Delta s_w - \Delta f. \quad (6)$$

The first term represents the weight of shear and bending material. The second term is the skin weight. The third term is the correction due to the skin's participation in resisting normal loads due to bending. The last two terms are corrections of the spar web and spar flange weights due to concentrated loads in the wing. All weights are in terms of all-up weight.

$$E = \frac{4}{15} \frac{f_c(3d_r + 2d_t)\delta_{sw}}{f_s(1+f_c/f_t)\delta_f} \dots \dots \dots (7)$$

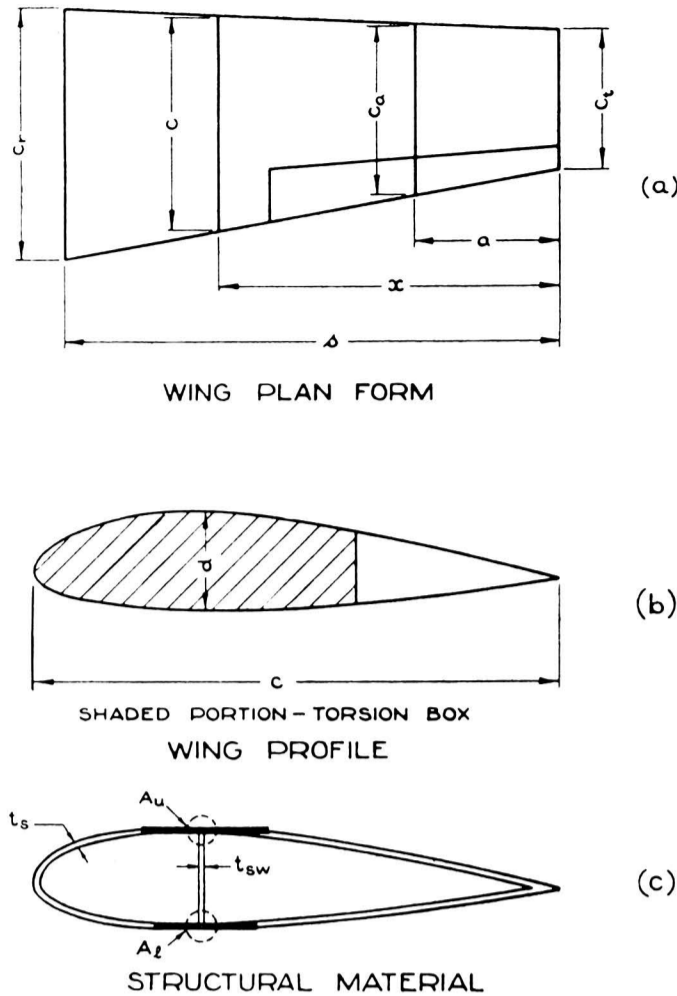


Fig. 1

$$J_e = \frac{4s}{3\pi} \dots \dots \dots (8)$$

$$H = \frac{s}{3} + \frac{2f_c d_r}{(1+f_c/f_t)Ns\delta_f} \dots \dots \dots (9)$$

$$K = 2\delta_s \left\{ \frac{a}{3} \left[c_a + g d_a + \frac{c_t + g d_t}{2} \right] + c_a d_a \left(\frac{1}{m} \log_e \frac{d_r}{d_a} + \frac{g}{n} \log_e \frac{c_r}{c_a} \right) \right\} \dots \dots \dots (10)$$

$$t^*_a = \frac{m\theta}{2Gh^2 t_c d_a} \left(\frac{1}{m} \log_e \frac{d_f}{d_a} + \frac{g}{n} \log_e \frac{c_f}{c_a} \right) \dots \dots \dots (11)$$

$$\Delta s = \frac{2\psi\delta_f t^*_a}{w} \left[\frac{a(c_t + 2c_a)}{6} + \frac{c_a d_a}{m} \log_e \frac{d_r}{d_a} \right] \dots \dots \dots (12)$$

$$\Delta s_w = \frac{2N\delta_{sw}}{Wf_s} \sum_{i=1}^n P_i(s-x_i) \dots \dots \dots (13)$$

$$\Delta f = \frac{2N\delta_f(1+f_c/f_t)}{Wf_c m^2} \sum_{i=1}^n P_i \left[(d_r - d_i) - d_i \log_e \frac{d_r}{d_i} \right] \dots \dots \dots (14)$$

Formulae for individual weights of spar flanges plus stringers, spar web, skin and ribs have also been worked out.⁴

These formulae, while providing the total weight, also enable the spanwise weight distribution to be obtained. This distribution is of great importance in wing stressing.

Numerical calculations carried out on over twenty aircraft have shown good discrimination as to the quality of the designs. TABLE 1 gives typical values.

TABLE 1

Types	r_i''	r_a	r_a/r_i''
Single-engined fighters	0.0475	0.1158	2.438
	0.0320	0.1296	4.050
	0.0477	0.1368	2.867
	0.0397	0.1488	3.747
Multi-engined civil aircraft	0.0353	0.1051	2.979
	0.0462	0.1166	2.524
	0.0468	0.1257	2.685
	0.0767	0.1293	1.686
	0.0760	0.1512	1.989
	0.0618	0.1568	2.537
Multi-engined bombers	0.0349	0.0943	2.702
	0.0415	0.1046	2.521
	0.0456	0.1085	2.382
	0.0501	0.1244	2.484

r_i'' = theoretical wing weight/all-up weight of aircraft

r_a = actual wing weight/all-up weight of aircraft
 r_a/r_i'' = actual wing weight/theoretical wing weight = correction factor.

r_a does not vary considerably—0.12 is the average figure.

r_i'' varies considerably showing that the designs chosen were not always the best ones.

r_a/r_i'' varies more than r_a , showing the difference in execution.

The Quadrilateral 'Shear' Panel

Concluded from p. 135

angles ϕ and ψ are

$$\frac{\bar{s}_1 P_{APB}}{I_P z^2} \cot \left(\frac{\phi + \psi}{2} \right) \text{ and } -\frac{\bar{s}_1 P_{APB}}{I_P z^2} \tan \left(\frac{\phi + \psi}{2} \right)$$

in directions parallel respectively to the external and internal bisectors of the angle PZQ .

8. The Trapezoidal Panel

If P recedes to infinity, AD , BC and QP become parallel (FIG. 4), so that the loading becomes uniform on AD and BC , and on sections parallel with them; also $\bar{s}_1 = \bar{s}_3$.

Since, by similar triangles, the perpendicular distance of any point in the panel from PQ is proportional to the depth of the panel at that point measured parallel with PQ , the well-known result follows that the "shear" flow in a trapezoidal panel is inversely proportional to the square of the depth.

To find the strain energy, we note that as P recedes, $\cot \alpha$ tends to the value $\frac{l}{PB}$ and l tends to infinity.

$$\frac{l}{PA} \text{ and } l \text{ tends to infinity.}$$

Substituting in (7) and proceeding to the limit, we find

$$U = \frac{\bar{s}_1^2}{2Gt^2} \left\{ 1 + \frac{2}{3(1+\nu)} (\cot^2 \beta + \cot \beta \cot \delta + \cot^2 \delta) \right\} \times \text{Volume} \dots \dots \dots (9)$$

9. 'Diamond' Bracing of a Quadrilateral Panel

It is sometimes necessary for access purposes to cut away a large part of a panel $ABCD$, and to resist the edge loads by a system of braces EF , FG , GH , HE (FIG. 5). The problem then arises of choosing the points E , F , G , H in such a way that the braces can resist the applied loads F_1 , F_2 , F_3 , F_4 by pure endload.

Assume that the points have been so chosen, and denote by $P(EF)$ the force in EF at E , produced by the force F_1 , and by $P(FE)$, the force in the same brace at F , produced by F_2 , with similar notation for the forces in the other braces.

Then it is clearly necessary that $P(EF) = -P(FE)$. Now the resultant of F_1 and F_2 must lie

along the diagonal DB , to balance the resultant of F_3 and F_4 . But F_1 is the equilibrant of $P(EF)$ and $P(EH)$, and F_2 is the equilibrant of $P(FE)$ and $P(FG)$; moreover the resultant of $P(EF)$ and $P(FE)$ is null.

It follows that the resultant of $P(EH)$ and $P(FG)$ must lie along BD , and hence that EH and FG must intersect on BD .

Similarly EF and HG must intersect on the diagonal AC .

An analogous argument shows that these conditions are also sufficient, i.e. if HE and FG intersect on BD , and EF and GH intersect on AC , then $P(EF) = -P(FE)$ and similarly for the other braces.

Moreover, it may be shown by geometry (projective geometry gives a neat proof) that if EH and FG meet on BD , then EF and GH meet on AC ; so that the necessary and sufficient condition that the diamond bracing may be able to resist the applied edge loads by pure endloads is that a pair of opposite members should intersect on a diagonal of the quadrilateral.

It follows that any two adjacent braces (say EH and EF) may be placed arbitrarily, and the position of the remaining two is then determined by producing EH to meet DB in J , joining JF , and producing it to meet CD in G .

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

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

SECTION 4—AERODYNAMICS AERODYNAMIQUE

A. General Generalités

(Continued from p. 118)

Axes	
<i>Body axes</i>	Axes liés à l'avion (m)
<i>Cross-wind axis</i>	Axe perpendiculaire au plan de symétrie de l'avion
<i>Drag axis</i>	Axe parallèle à la traînée
<i>Lateral axis</i>	Axe parallèle à la force latérale
<i>Lift axis</i>	Axe parallèle à la portance
<i>Longitudinal axis</i>	Axe de roulis
<i>Normal axis</i>	Axe de lacet
<i>Wind axes</i>	Axes de coordonnées liées au vent
Centre of pressure	Centre de poussée (m)
Forces	
<i>Cross wind force</i>	Force latérale (f)
<i>Drag</i>	Traînée (f)
<i>Cooling drag</i>	Traînée de radiateur
<i>Form drag</i>	Traînée de forme
<i>Induced drag</i>	Traînée induite
<i>Pressure drag</i>	Traînée de pression
<i>Profile drag</i>	Traînée de profil
<i>Surface friction drag</i>	Traînée de frottement
<i>Skin friction drag</i>	
<i>Lateral force</i>	Force latérale
<i>Normal force</i>	Force normale
Interference	Interaction (f)
Lift	Portance
<i>Aerodynamic lift</i>	Portance aérodynamique (f)
<i>Total lift</i>	Portance totale
Linear velocities	Vitesses lineaires
<i>Air speed</i>	Vitesse de l'air (f)
<i>Lateral velocity</i>	Vitesse de dérapage
[<i>Rate of side-slip</i>]	Taux de dérapage (m)
<i>Limiting velocity</i>	Vitesse limite (dans des conditions données)
<i>Longitudinal velocity</i>	Vitesse suivant l'axe longitudinal de l'avion
<i>Normal velocity</i>	Vitesse suivant l'axe de lacet
<i>Terminal velocity</i>	Vitesse limite maximum
Moments	
<i>Damping moment</i>	Moment d'amortissement (m)
<i>Disturbing moment</i>	Moment perturbateur
<i>Hinge moment</i>	Moment de charnière
<i>Pitching moment</i>	Moment de tangage
<i>Restoring moment</i>	Moment stabilisateur
<i>Rolling moment</i>	Moment de roulis
<i>Yawing moment</i>	Moment de lacet
No-lift direction	Direction de portance nulle (f)
Scale effect	Effet d'échelle (m) (Influence du nombre de Reynolds)

B. Stability Stabilité

Damping factor	Facteur d'amortissement (m)
Divergence	Divergence (f)
<i>Lateral divergence</i>	Divergence latérale
<i>Longitudinal divergence</i>	Divergence longitudinale
Instability	Instabilité (f)
<i>Directional instability</i>	Instabilité de route (f)
<i>Longitudinal instability</i>	Instabilité longitudinale

Rolling instability
[*Lateral instability*]
Spiral instability
Manoeuvre margin
with stick fixed
Manoeuvre margin
with stick free
Manoeuvre point
with stick fixed
Manoeuvre point
with stick free
Neutral point
with stick fixed
Neutral point
with stick free
Oscillations
Lateral oscillation
Longitudinal oscillation
Period
Phugoid oscillation
Stable oscillation

Unstable oscillation

Stability
Directional stability
Lateral stability

Longitudinal stability

Static stability
Weathercock stability
Stability derivatives
Rotary derivatives

Static margin
with stick fixed
Static margin
with stick free
Subsidence

C. Performance Performances

Air speed	Vitesse réelle (f)
[<i>True air speed (T.A.S.)</i>]	
<i>Approach speed</i>	Vitesse d'approche
<i>Equivalent air speed [E.A.S.]</i>	Equivalent de vitesse (m)
<i>Indicated air speed [I.A.S.]</i>	Vitesse indiquée
<i>Landing speed</i>	Vitesse d'atterrissage
<i>Maximum flying speed</i>	Vitesse maximum
<i>Minimum flying speed</i>	Vitesse minimum
<i>Rectified air speed [R.A.S.]</i>	Vitesse corrigée
<i>Safety speed</i>	Vitesse de sécurité
<i>Stalling speed</i>	Vitesse de décrochage
<i>Take-off speed</i>	Vitesse de décollage
<i>Indicated stalling speed</i>	Vitesse indiquée de décrochage
Cruising threshold	Vitesse minimum de croisière
Ceiling	Plafond (m)
<i>Absolute ceiling</i>	Plafond absolu
<i>Cruising ceiling</i>	Plafond de croisière
<i>Service ceiling</i>	Plafond d'utilisation

Endurance
Prudent limit of endurance
Point of no return

Ground speed
Performance
Position error
Radius of action
Range
Most economical range
Range at maximum weak-mixture power
Rate of climb
Screen

Speed course

D. Fluid Motion **Mouvement des Fluides**

Boundary layer
Separation point
Transition point
Circulation
Compressibility drag
Eddy
Laminar flow
Mach number
Flight mach number
Pressure
Dynamic pressure
[Kinetic pressure]
Reference pressure
Static pressure
Total head
Reynolds number
Shock wave
Stagnation point
Streamline motion
Subsonic speed
Supersonic speed
Transonic range
Turbulent flow
Vortex
Line vortex
Point vortex

Trailing vortex
Vortex sheet
Vortex street

Vorticity
Wake

E. Model Testing **Essais de maquette**

Aerodynamic balance
Rolling balance
Six-component balance
Three-component balance
Air interchanger

Cascades

Collector
Contraction ratio
Diffuser
Diffuser cone angle
Dynamic model
Elastic model

Fan straighteners

Honeycomb
[Straighteners]
Nozzle
Seaplane tank
Sting
Water channel

Water tunnel

Autonomie (f)
Autonomie pratique
Demi autonomie pratique—(Le point le plus éloigné de la base que l'avion peut atteindre en assurant son retour avec une marge de sécurité en combustible)
Vitesse par rapport au sol
Performance (f)
Erreur de statique (m)
Demi-rayon d'action en air calme
Rayon d'action (m)
Rayon d'action économique
Rayon d'action maximum avec mélange pauvre
Vitesse ascensionnelle (f)
Obstacle (réel ou imaginaire) au décollage et à l'atterrissage (m)
Base pour déterminer la vitesse

Couche limite (f)
Point de décollement (m)
Point de transition
Circulation (f)
Traînée (f) due à la compressibilité
Remous, autour d'un tourbillon (m)
Écoulement laminaire (m)
Nombre de Mach (m)
Nombre de Mach du vol
Pression (f)
Pression dynamique du point d'arrêt

Pression dynamique de référence
Pression statique
Pression totale
Nombre de Reynolds (m)
Onde de choc (f)
Point d'arrêt (m)
Écoulement laminaire
Vitesse subsonique (f)
Vitesse supersonique
Domaine transsonique (m)
Écoulement turbulent
Tourbillon (m)
Tourbillon en ligne
Section plane (f) d'un tourbillon en ligne dans un écoulement à deux dimensions
Tourbillon libre
Surface tourbillonnaire (f)
Allée tourbillonnaire (f); disposition régulière de tourbillons en ligne sur deux rangées à peu près parallèles
Tourbillonnement
Sillage (m)

Balance aérodynamique (f)
Balance de roulis
Balance à six composantes
Balance à trois composantes
Dispositif (m) de prises d'air additionnelles dans les souffleries en circuit fermé (m)
Aubes (f) ou déflecteurs (m) dans les tunnels (m) aérodynamiques
Collecteur (m)
Rapport de contraction (m)
Diffuseur (m)
Angle du cône du diffuseur (m)
Maquette pour essais dynamiques (f)
Maquette pour essais d'aéroélasticité reproduisant les inerties et les rigidités
Déflecteurs-redresseurs (m) en aval ou amont du ventilateur (m)
Déflecteurs-redresseurs de soufflerie (f) en nid d'abeilles
Convergent (m)
Bassin de carène (m)
Bras (m), support de maquette (m)
Canal (m) pour essais (m) hydrodynamiques
Soufflerie à eau (f)

Whirling arm
Wind tunnel
Closed-jet wind tunnel
Closed-jet, return flow
Closed-jet, non-return flow
Compressed-air wind-tunnel
[Variable-density wind-tunnel]
Free-flight wind-tunnel
High-speed wind-tunnel
Non-return-flow wind-tunnel
Open-jet wind-tunnel
Open-jet return flow
Open-jet, non-return flow
Supersonic wind-tunnel
Vertical wind-tunnel

SECTION 5—HEAVIER-THAN-AIR AIRCRAFT (AERODYNES) **AERONEFS PLUS LOURDS QUE L'AIR (AERODYNES)**

A. Complete Aircraft **Divers Types d'Aéronefs**

Aeroplane
Airplane
Pusher aeroplane
Tractor aeroplane
Amphibian
Landplane
Seaplane
Float seaplane
Flying boat
[Boat seaplane]
Shiplane
Glider
Sailplane
Towed glider

Kite
Monoplane
High-wing monoplane
Low-wing monoplane
Mid-wing monoplane
Parasol monoplane
Multiplane
Ornithopter
Rotorcraft

Aéroplane (m), Avion (m)

Aéroplane (m) à hélice propulsive
Aéroplane à hélice tractive
Amphibie (m)
Avion (m)
Hydravion (m)
Hydravion à flotteurs
Hydravion à coque

Avion embarqué
Planeur (m), cellule
Planeur (m), vol à voile
Planeur remorqué—ne volant que remorqué
Cerf-volant (m)
Monoplan (m)
Monoplan à aile haute
Monoplan à aile basse
Monoplan à aile médiane
Monoplan parasol (m)
Multiplan (m)
Avion à ailes battantes
Aérodynes à voilures tournantes*

B. Shape and Disposition of Surfaces **Forme et Disposition des Surfaces**

Aerofoil
Slotted aerofoil
Slat
Aerofoil section
Angles
Aileron angle
Elevator angle
Flap angle
Rudder angle
Décalage

Dihedral
Sweep-back and sweep-forward
Tail setting angle
Wash-in

Wash-out

Areas
Gross wing area
Net wing area
Aspect ratio
Camber
Centre line
Centre line camber
Mean camber
Chord
[Chord length]
Chord line
Chord
Chord position

Corps aérodynamique (m)
Profil à fente (m)
Bec à fente, fente avant
Profil parallèlement au plan de symétrie

Angle de braquage d'aileron
Angle de braquage de profondeur
Angle de braquage des volets
Angle de braquage du gouvernail
Décalage, angle entre les cordes des plans inférieur et supérieur d'un biplan, mesuré parallèlement au plan de symétrie
Dièdre (m)
Flèche (f) arrière et fleche avant
Calage du plan fixe
Augmentation d'incidence à l'extrémité de l'aile
Diminution d'incidence à l'extrémité de l'aile
Surfaces
Surface totale de l'aile
Surface nette de l'aile
Allongement (m)
Cambrure (f)
Squelette (m) du profil
Cambrure du squelette

Corde (f), longueur de corde

Corde

Position de la corde donnée par son inclinaison θ et les coordonnées x, y, z , du point situé au quart de la corde. (Les conventions de signes sont données dans l'appendice. L'origine des coordonnées est un point fixe du plan de symétrie)

(To be continued)

* Cyclogyro, Gyroplane, Helicopter, Paddleplane, q.v. Section 6—Rotorcraft.

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 COUNCIL
Ottawa

AERONAUTICAL REPORTS

AR-7. Wall Interference in Wind Tunnels of Closed Rectangular Section. By J. Sanders and J. R. Pounder. 1949.

In this report, theories of the wall interference on aerofoils and symmetrical bodies in wind tunnels of closed rectangular section are reviewed and extended.

In Part 1, exact and general expressions are derived, on the basis of lifting-line theory, for the interference on the lift, drag, lift distribution, and rolling and yawing moments of an arbitrary three-dimensional aerofoil. Part 2 contains lift, pitching-moment, hinge-moment, and pressure-distribution corrections for a two-dimensional aerofoil spanning the tunnel. The theories of Parts 1 and 2 are combined and extended in Part 3 to obtain streamline curvature corrections to the lift, pitching-moment, hinge-moment, and lift distribution on a wing with a control surface, as well as downwash and tailsetting corrections. Parts 2 and 3 also contain blockage and pressure-gradient corrections for two- and three-dimensional symmetrical bodies respectively.

At the end of the report may be found tables and graphs showing the results of calculations (described in Part 4), as well as a comprehensive bibliography.

U.S.A.

NATIONAL ADVISORY COMMITTEE FOR
AERONAUTICS

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TECHNICAL REPORTS

1949

Report 922. Characteristics of Low-Aspect-Ratio Wings at Supercritical Mach Numbers. By John Stack and W. F. Lindsey. (10 cents.)

The separation of the flow over wings precipitated by the compression shock that forms as speeds are increased into the supercritical Mach number range has imposed serious difficulties in the improvement of aircraft performance. These difficulties arise principally as a consequence of the rapid drag rise and the loss of lift that causes serious stability changes when the wing shock-stalls. Favourable relieving effects due to the three-dimensional flow around the tips were obtained and these effects were of such magnitude that it is indicated that low-aspect-ratio wings offer a possible solution of the problems encountered.

Report 923. Effect of Afterbody Length and Keel Angle on Minimum Depth of Step for Landing Stability and on Take-off Stability of a Flying Boat. By Roland E. Olson and Norman S. Land. (15 cents.)

Tests were made to fill partly the need for information on the effect of afterbody dimensions on the hydrodynamic stability of a flying boat in smooth water. The dimensions investigated were depth of step, angle of afterbody keel, and length of afterbody. An analysis of the data showed that as either the afterbody length or keel angle was increased an accompanying increase in depth of step was required in order to maintain adequate landing stability. A comparison of models with differing afterbody lengths but with each having a depth of step which provides adequate landing stability revealed that there was no marked change in the take-off stability. A similar comparison for the models with differing keel angle showed that increases in keel angle resulted in a large increase in the angle of stable trim for take-off and some increase in the range of stable centre-of-gravity location for take-off.

A large change in gross load had little effect on the landing stability.

The landing-test results have been reduced to an empirical formula giving the minimum depth of step in terms of afterbody length and keel angle. This formula is compared with results from other tank tests, and the correlation is fairly good. The formula thus becomes of use in preliminary design.

Report 924. Application of Theodorsen's Theory to Propeller Design. By John L. Crigler. (15 cents.)

A theoretical analysis is presented for obtaining by use of Theodorsen's propeller theory the load distribution along a propeller radius to give the optimum propeller efficiency for any design condition. The efficiencies realized by designing for the optimum load distribution are given in graphs, and the optimum efficiency for any design condition may be read directly from the graph without any laborious calculations. Examples are included to illustrate the method of obtaining the optimum load distributions for both single-rotating and dual-rotating propellers.

Report 925. Stability Derivatives at Supersonic Speeds of Thin Rectangular Wings with Diagonals Ahead of Tip Mach Lines. By Sidney M. Harmon. (15 cents.)

Theoretical results are obtained, by means of the linearized theory, for the surface-velocity-potential functions, surface-pressure distributions, and stability derivatives for various motions at supersonic speeds of thin flat rectangular wings without dihedral. The investigation includes steady and accelerated vertical and longitudinal motions and steady rolling, yawing, sideslipping, and pitching for Mach numbers and aspect ratios greater than those for which the Mach line from the leading edge of the tip section intersects the trailing edge of the opposite tip section. The stability derivatives are derived with respect to principal body axes and then transformed to a system of stability axes. In the case of yawing, a treatment for the infinitely long wing which takes account of the spanwise variation in the stream Mach number is extended to the finite wing, and a plausible, although not rigorous, solution is obtained for the wing tip effects.

The results for this investigation shows that positive yawing at supersonic speeds may produce a negative rolling moment in contrast to the behaviour at subsonic speeds where a positive rolling moment would be produced. The attainment of supersonic speed should produce a significant change in the positive direction of the yawing moment per unit rolling velocity.

Report 926. Sound-Level Measurements of a Light Airplane Modified to Reduce Noise Reaching the Ground. By A. W. Vogley. (10 cents.)

An army liaison-type aeroplane, representative of personal aeroplanes in the 150 to 200 horsepower class, has been modified to reduce propeller and engine noise according to known principles of aeroplane-noise reduction. Noise-level measurements demonstrate that, with reference to an observer on the ground, a noisy aeroplane of this class can be made quiet—perhaps more quiet than necessary. In order to avoid extreme and unnecessary modifications, acceptable noise levels must be determined.

Report 927. Appreciation and Prediction of Flying Qualities. By William H. Phillips. (30 cents.)

The material given in this report summarizes some of the results of recent research that will aid the designers of an aeroplane in selecting or modifying a configuration to provide satisfactory stability and control characteristics. The requirements of the National Advisory Committee for Aeronautics for satisfactory flying qualities, which specify the important stability and control characteristics of an aeroplane from the pilot's standpoint, are used as the main topics of the report. A discussion is given of the reasons for the requirements, of the factors involved in obtaining satisfactory flying qualities, and of the methods used in predicting the stability and control characteristics of an aeroplane. This material is based on lecture notes for a training course for research workers engaged in aeroplane stability and control investigations.

Report 928. Analysis of Performance of Jet Engine from Characteristics of Components II—Interaction of Components as Determined from Engine Operation. By Arthur W. Goldstein, Sumner Alpert, William Beede, and Karl Kovach. (20 cents.)

In order to understand the operation and the inter-

action of jet-engine components during engine operation and to determine how component characteristics may be used to compute engine performance, a method to analyse and to estimate performance of such engines was devised and applied to the study of the characteristics of a research turbojet engine built for this investigation. An attempt was made to correlate turbine performance obtained from engine experiments with that obtained by the simpler procedure of separately calibrating the turbine with cold air as a driving fluid in order to investigate the applicability of component calibration. After correction for blade-tip leakage, the turbine-characteristic curves of weight flow and total-pressure ratio checked with the results from cold-air component calibration. Some discrepancies in efficiency were noted between the two sets of experiments. Despite such errors, turbine-compressor interaction may be accurately determined but some error in exhaust pressure may be involved.

From analysis of the component calibrations, predictions that investigation of the engine without modifications would not cover an adequate range of turbine performance were verified by the engine performance. The range of turbine operation was extended by study of the engine with modifications to the compressor.

The system of analysis was also applied to prediction of the engine and component performance with assumed modifications of the burner and bearing characteristics, to prediction of component and engine operation during engine acceleration, and to estimates of the performance of the engine and the components when the exhaust gas was used to drive a power turbine.

GREAT BRITAIN

AERONAUTICAL RESEARCH COUNCIL

H.M. Stationery Office, London

R. & M. No. 2379. Handling Tests on the Curtiss H-75, and Comparative Aileron Tests on the Curtiss H-75, Spitfire and Gloster F.5/34. By M. B. Morgan, D. E. Morris and F. J. Bigg. April, 1940. (6s.)

Considerable interest was aroused by a report of an A. & A.E.E. pilot on brief handling tests, made in France, of the Curtiss H-75. This single-seater fighter appeared to have remarkably good controls, the ailerons in particular being fairly light at high speeds, in marked contrast to the Spitfire, whose ailerons have been described as 'almost immovable at speeds above 300 m.p.h.'

It was decided to borrow a Curtiss H-75 from France for more extensive tests; the Royal Aircraft Establishment was asked to pay particular attention to lateral control at high speeds.

The handling tests covered the following points: ease of take-off and landing; directional and longitudinal trim; 'one-control' tests, flat turns and sideslips, behaviour at the stall; high-speed dives; harmony and 'feel' of the controls. The pilots also gave their views on cockpit layout.

Rough measurements of the stick force to apply about quarter-aileron and the corresponding time to 45 deg. bank were made on the Curtiss H-75, Spitfire and Gloster F.5/34 over the speed range 150 m.p.h. to 400 m.p.h.

Finally aerial combats were staged between the Curtiss H-75 and the Spitfire, and pilots were asked to give their opinions on the respective merits of the Curtiss H-75, Spitfire, Hurricane and Gloster F.5/34.

The aircraft is very easy to fly, and the handling qualities are exceptionally good.

Take-off and landing are straightforward. At approach speeds there is a high degree of longitudinal stability; at climbing speeds and above the longitudinal stability is almost neutral.

Fin area and dihedral are adequate. There is good control up to the stall, at which a wing drops sharply. No flutter, vibration or 'snaking' develop in a dive of 400 m.p.h.

The controls are exceptionally well harmonized. They are not too light at low speeds and do not stiffen up unduly at high speeds.

The cockpit layout is very satisfactory.

At 400 m.p.h. indicated airspeed the following stick forces are required to displace the ailerons; times to 45 deg. bank are also given.

Curtiss H-75	23 lb. for 1/4 displacement ($Kb_2 = -0.105$) 5 sec. to 45 deg. bank.
Spitfire	57 lb. for 1/5 displacement ($Kb_2 = -0.14$) 4 sec. to 45 deg. bank.
Gloster F.5/34	23 lb. for 1/4 displacement ($Kb_2 = -0.035$) 1.5 sec. to 45 deg. bank.

Owing to the high stick force more than 1/5 aileron cannot be applied on the Spitfire at 400 m.p.h.,

whereas nearly 3/4 aileron can be applied on the Curtiss H-75 and Gloster F.5/34 (with a corresponding reduction in the times to 45 deg. bank).

A large part of the lightness of the Curtiss ailerons, compared with those of the Spitfire, is due to bigger differential and greater stick travel.

At 400 m.p.h. the Curtiss is far superior to the Spitfire in a diving attack owing to its lighter ailerons. In a dog-fight at 250 m.p.h. the Curtiss is again superior because its elevator control is not over-sensitive and the all-round view is more extensive; but the Spitfire pilot can break off combat if he desires owing to the higher top speed of his aircraft.

R. & M. No. 2401. Note on the Increase of Drag of an Aerofoil Due to the Thickening of the Boundary Layer behind a Shock Wave. By A. D. Young and Miss E. Young. August 1946. (1s.).

Calculations have been made of the theoretical drag coefficients of two aerofoil sections (EC 1250 and Mustang section) at Mach numbers in excess of that corresponding to the shock stall, using the measured pressure distributions. It was argued that the differences between these drag coefficients and the corresponding coefficients for incompressible flow would provide a reliable estimate in each case of the increment in drag coefficient due to the thickening of the boundary layer behind the shock wave. The results show this increment to be of the order of 0.001. Whilst this is not negligible, it is considerably less than the measured increase associated with the full development of the shock waves.

R. & M. No. 2404. Wind-tunnel Tests on an Aircraft Designed for Supersonic Speeds. July 1945. (5s.).

This report combines the results of tests made in two different wind tunnels at the Royal Aircraft Establishment, Farnborough, on an aircraft designed for supersonic speeds.

PART I. Describes high-speed and high Reynolds-number tests made to check the stability at high speeds, and the low-speed landing condition respectively.

PART II. Describes low-speed tests made on the wing alone in order to check scale effect on lift and drag, and for comparison with previous low-speed tests on a complete model.

R. & M. No. 2405. Stresses in a Stiffened Circular Cylinder under Concentrated Axial Loads. By D. C. Allen. January 1946. (2s.).

Solutions for the stress distribution in a long cylindrical shell of circular cross-section subjected to axial loads at four longerons have been obtained for two symmetrical loading cases—tension and bending action. From these any symmetrical loading condition can be deduced. The solution is in the form of an infinite series, but convergence is rapid except close to the root, and even when large numbers of terms are required the difficulty of computation of the higher terms is not great. The calculated distribution for a particular case has been compared with some tests results on a non-circular fuselage, and general agreement obtained.

R. & M. No. 2408. The Investigation of Air Loads in Flight from Measurements of Strain in the Structure. By J. Taylor. November 1945. (1s.).

Strain measurements in flight involve considerably more work than on ground tests and should be restricted to problems which cannot be solved by ground tests.

Limited experience available suggests that for most flight work the overall bending and shear actions at each of about five sections of a major component are all that is required. These can be determined by suitable selection of positions of gauges, with no more than four or eight measuring stations at each section.

It is advisable to check any particular installation by ground tests using known loads.

R. & M. No. 2412. Two-dimensional Tests on a 15 per cent Thick Symmetrical Roof-top Aerofoil with 20 per cent Plain Flap in the National Physical Laboratory 13 ft. x 9 ft. Wind Tunnel. By F. Cheers, W. S. Walker and C. R. Taylor. June 24, 1946. (2s.).

A series of tests was carried out in the 13 ft. x 9 ft. wind tunnel at the National Physical Laboratory on a 15 per cent thick symmetrical roof-top aerofoil fitted with a 20 per cent plain flap, in order to obtain information about the increase of the low-drag range to be gained by deflecting the flap and to extend to higher Reynolds numbers earlier work on the relations between theoretical and experimental characteristics of a wing with flap.

With flap at 0 deg. the lift, drag, and pitching

moments up to the stall were measured at speeds up to 180 ft./sec. ($R=2.88 \times 10^6$). A few tests were also made with small flap deflexions and incidences up to 4 deg. With the flap at 0 deg. the low-drag range is small, and at 180 ft./sec. the wing stalls at 12 deg. incidence ($C_L=1.05$). Deflexion of the flap increased the low-drag range, but this series of tests was not completed owing to failure of the model. The values of dC_L/da and $dC_L/d\eta$ were 6.4 and 2.9 respectively.

Visualization of the boundary-layer flow revealed that laminar separation was taking place at 0 deg. incidence up to the top speed of the tunnel ($R=3.36 \times 10^6$). On the upper surface the separation disappeared at 2 deg. incidence, but on the lower surface it persisted up to 4 deg. or 6 deg. The flow was very sensitive, and attempts to repeat readings were frequently unsuccessful.

R. & M. No. 2413. Tests on a 5 per cent Biconvex Aerofoil in the Compressed-Air Tunnel. By D. H. Williams and A. H. Bell. October 19, 1945. (2s.).

A symmetrical 5 per cent biconvex aerofoil has been tested from $R=0.3 \times 10^6$ to $R=7.5 \times 10^6$. No scale effect was found on C_L . To show the effect of camber, comparative curves are given for circular-back aerofoils. C_{Lmax} increases linearly with camber from 0.7 for the symmetrical wing to 1.18 for a wing with 6 per cent camber. The aerofoil was also tested with a 15 per cent split flap. With flap, C_{Lmax} was 1.35.

R. & M. No. 2414. The Determination of Propeller Efficiency in Flight—Preliminary Tests with a Rotol Propeller. By K. Eyre. July 1946. (2s. 6d.).

In connexion with the proposed flight programme to determine the efficiency of various propeller designs at high forward speed, preliminary flight tests have been made using a Spitfire IX aircraft equipped with a standard Rotol propeller and Merlin 70 engine, in order to test the method.

The aircraft was fitted with a pitot-comb installation behind the propeller for the measurement of thrust; a description is given of this and the associated recording apparatus. Torque was determined from observed engine conditions and test bench calibrations.

Flights were made at a constant true forward speed of 392 m.p.h. and engine speed of 3,000 r.p.m., giving a tip Mach number of 0.98, but at four different values of engine power. As the aircraft passed through the test height of 25,000 ft. recordings were made of thrust and the engine conditions. The efficiency was calculated for each of the four powers and the values obtained lie within $\pm 2\frac{1}{2}$ per cent of the theoretical free-air efficiency.

The test instruments functioned in a satisfactory manner and a suitable experimental technique was established. It is thought that a maximum propeller efficiency can be measured to within ± 5 per cent., at a forward speed of 600 m.p.h. at 25,000 feet.

GREAT BRITAIN

THE COLLEGE OF AERONAUTICS Cranfield, Bletchley, Bucks.

Addendum to Report No. 12. The Aerodynamic Derivatives with Respect to Sideslip for a Delta Wing with Small Dihedral at Supersonic Speeds. By Squadron Leader J. H. Hunter-Tod and A. Robinson. December 1950.

The axis of a delta wing under sideslip is not aligned with that of the apex Mach cone. In calculating the forces by first-order methods this fact may be ignored when the wing is at zero incidence, but when it is at incidence first order effects are introduced due to the distortion of the existing flow. In the original paper the latter were ignored; the corresponding forces are derived in the present addendum.

Neglecting leading edge suction the terms in the three sideslip derivatives dependent on incidence are discontinuous in changing from the quasi-subsonic to the definitely supersonic condition, generally involving a marked decrease in the numerical value and for the rolling derivative always a change of sign.

The leading edge suction due to incidence drops rapidly to zero as an edge approaches the apex Mach cone with the result that the suction contributions to the derivatives become indefinitely large in the limiting case though the actual forces are small.

Report No. 42. The Equations of Motion and Energy and the Velocity Profile of a Turbulent Boundary Layer in a Compressible Fluid. By A. D. Young. January 1951. (5s.).

As far as the author is aware the derivation of the equations of motion and energy for a turbulent boundary layer in a compressible fluid have not as

yet been given in detail in any publication. To meet a possible need in this connexion this paper puts on record the analysis underlying the equations quoted by the author in Chapter X of the forthcoming Vol. III of Modern Developments in Fluid Dynamics.

In the absence of further experimental data and of an adequate knowledge of the physics of turbulence, particularly in high-speed flow, it is impossible to make use of these equations except in a few simple cases. One of these cases is considered here, viz. mean parallel flow in the boundary layer on a flat plate with the Prandtl number equal to unity. The object was to investigate the effect of compressibility and heat transfer on the form of the velocity profile of the boundary layer. The crude method that serves for a theory in deriving the well-known 'log' law in an incompressible fluid is adapted here to a compressible fluid, the underlying justification being that since the method gives something close to the right result in the first instance, it should indicate with reasonable accuracy any change that arises due to compressibility.

It is concluded that for Mach numbers of the order of 2.5 or less and for a wide range of heat transfer conditions the form of the velocity profile in the turbulent boundary layer will differ very little from that for an incompressible fluid and the same Reynolds number. This result is in agreement with existing experimental results. For higher Mach numbers, however, small differences will become apparent particularly for cases of considerable heat transfer from the surface.

PROFESSIONAL PUBLICATIONS

Under this heading are given each month the principal articles of aeronautical interest appearing in the current issues of the Journals of the leading Professional Societies and Institutions

Institute of the Aeronautical Sciences (U.S.A.) JOURNAL OF THE AERONAUTICAL SCIENCES (Monthly)

Vol. 18, No. 3, March 1951

Turbulent Boundary Layer in Compressible Fluids. E. R. Van Driest
First- and Second-Order Theory of Supersonic Flow Past Bodies of Revolution. M. D. Van Dyke
Methods for Calculating the Flow in the Trefftz-Plane Beliefs Supersonic Wings. P. A. Lagerstrom and M. E. Graham
Purely Rolling Oscillations of a Rectangular Wing in Supersonic Flow. Ting-Yi Li
Experimental and Theoretical Studies of Flame-Front Stability. G. H. Markstein

AERONAUTICAL ENGINEERING REVIEW (Monthly)

Vol. 10, No. 3, March 1951

Practical Aspects of Turbojets in Transport Aircraft. R. T. Holland and E. L. Aywer
Colorado University's Steam-Jet-Powered Supersonic Wind Tunnel Interaction Curves for the Critical Loads on Continuous Beam-Columns. E. Rottmayer

The Institution of Production Engineers JOURNAL (Monthly)

Vol. 30, No. 4, April 1951

Steel—the Engineer's Clay. F. Westall
The Place of the Metallurgist in Production Engineering. E. R. Gadd

The Institution of Engineering Inspection ENGINEERING INSPECTION (Quarterly)

Vol. XIV, No. 4, Winter 1950-1

The Production and Inspection of Plain Bearings. H. Roth
Inspection in Welding. F. C. Cocks
Vacuum Coating. L. Holland

Society of Automotive Engineers (U.S.A.) SAE JOURNAL (Monthly)

Vol. 59, No. 3, March 1951

Summaries:
Comparison of Turbine-Propeller Engines with Various Cycle Arrangements for Subsonic Flight Speeds. T. F. Nagey
Low-Temperature Properties of Ferrous Materials. L. D. Jaffe, P. R. Kosting, A. F. Jones, J. I. Bluhm, A. Hurlich and J. F. Wallace

The Society of Licensed Aircraft Engineers THE TECHNICAL INSTRUCTOR (Monthly)

Vol. VI, No. 3, March 1951

Accident Investigation. Air-Commodore Vernon Brown

Royal Aeronautical Society JOURNAL (Monthly)

Vol. 55, No. 484, April 1951

Clear Air Turbulence over Europe. G. S. Hislop
Measurement of Jet Engine Thrust. B. Jakobsson
86th Annual Report of the Council, 1950-1951

The Library Shelf

Precise Measurement — Space Travel — Fluids and Pneumatics — a Reference Book

Engineering Metrology. By K. J. Hume. [Macdonald & Co. Ltd., 43 Ludgate Hill, E.C.4. 18s.]

Engineering metrology, or dimensional measurement in engineering as it may otherwise be termed, is a subject which has become of increasing importance to production engineers during the past fifteen years or so. This has been recognized by the Institutions of Mechanical and Production Engineers and it is now included as a subject in their Associate Membership examinations, and also for the Higher National Certificate. Up to the present time, however, books dealing with the subject have been few, and the above book is a welcome acquisition to the number, as it provides an up-to-date survey of a subject in which progress is rapid. Mr Hume is well qualified to write on the subject as, in addition to his experience in his present post as Metrology Superintendent of the de Havilland Engine Co. Ltd., he has had a number of years' experience in the Metrology Division of the National Physical Laboratory and at Hilger and Watts Ltd.

Turning now to the book itself one can say that it is well written and very well illustrated, and is extremely good value at the, nowadays, modest price of 18s. The book is intended for production engineers concerned with precise measurement as well as for technical college students. The scope covered is wide, and includes the affiliated subjects of Limits and Fits, Screw Thread Standards, Limit Gauging Practice, Limit Gauge Manufacture, etc. in addition to the purely metrological branches such as Standards of Measurement, Optical Projectors and Microscopes, Angular and Linear Measurement, Measurement of Straightness, Flatness and Squareness, Alignment Testing, Screw Thread Measurement, Surface Finish, etc., and last, but not least, a valuable chapter on Gauge and Instrument Design.

In view of the very wide scope covered, the author has dealt very well with the mass of information available to incorporate as much as he has done within the 280 or so pages of the book. One questions the advisability, however, of using valuable space to give the basic principles of elementary trigonometry and algebra. Apart from this minor criticism one has no hesitation in recommending this book.

L. W. N.

The Conquest of Space. By Chesley Bonestell and Willy Ley. [Sidgwick and Jackson. 18s.]

Although we, personally, cannot credit the possibility of interplanetary travel, that is to say journeys to predetermined destinations, we admit that 'escape' from this planet is within sight. However, more learned heads than ours appear to be convinced of the practicability of, at least, regular 'out-and-home' trips to the moon in our lifetime. But whatever one's opinions of the possibility—or desirability for that matter—of space travel this is a fascinating book. It in reality forms two books in one: the illustrations of Chesley Bonestell and the text of Willy Ley.

The paintings—there are forty-eight—are reproduced in colour and in half-tone. The artist, who was at one time an architectural illustrator, has prepared them with a rare combination of imagination and painstaking accuracy both in perspective and in the astronomical details. There are three series of pictures: the first depicts rocket

journeys at great altitudes from and around the earth; the second is a series of sixteen scenes from an imaginary moon trip; while the remainder, almost half, are paintings of the planets compiled from astronomical knowledge as it exists today. The last-named are, to our thinking, quite the most intriguing part of the book. The colourful scenes are so plausibly presented that it is difficult to realize that they are, in some cases, constructed from the slenderest of evidence. There is one curious, unexplained inclusion, and that is a very lovely picture of the double star Mira as seen from a possible planet—this picture is unique because all the others deal with subjects within the solar system.

The text is of a fairly elementary nature and probably contains little for the interplanetary enthusiast, although it is of interest to the ordinary technical reader. There are numerous facts about the solar system that are not readily obtainable, while the information on rocketry is also useful. There is considerable inconsistency and incompleteness in this descriptive matter and the irritation of the *non sequitur* is not absent. Failings apart, however, this book is very good value and contains an astonishing number of illustrations for the money.

J. H. S.

THREE BOOKS ON AIR AND FLUID SYSTEMS

Fluid Pressure Mechanisms. H. G. Conway [Pitman. 25s.]

Air Systems for Aircraft. C. A. H. Pollitt [Pitman. 25s.]

Air Compressors, Control and Installation. P. C. Bevis [Pitman. 20s.]

These three books have common denominators in both their publisher and their general subject matter, although each presents an entirely different approach to the subject of pneumatics as applied to aircraft.

The author of the first book, Mr H. G. Conway, is a fluid engineer of many years' experience who has, as our readers know well, a gift rare among practical engineers of expressing himself in print as clearly and to the point as he does verbally at a conference. Drawing upon his wide knowledge of hydraulic and pneumatic system design for aircraft he has written a most comprehensive book about the machinery of such installations—although it should be clearly understood that there is no question of the matter being solely applicable to the aeronautical industry.

The book is, in effect, something of a catalogue, for it deals first, component by component, with the units that go to make up a fluid system and then goes on to outline the main features of various types of system. The subject matter is strictly limited to the mechanics of both the units and the systems, the author having severely disciplined himself into avoiding any discussion of details or of manufacture. Some five hundred devices are covered and the concise, lucid text is made even more clear by several hundred excellent diagrams.

The author of the second book has included a very varied selection of items in one hundred and fifty-odd pages: the Hymatic pneumatic system and equipment; the Dunlop brake and gun-firing systems, together with some of their other pneumatic units; the Teddington radiator-flap and supercharger controls; the Boeing B-29 'snap-opening' bomb door circuit; B.T.H.

Napier and Pesco pumps; a general chapter on air-conditioning and cabin pressurizing, including several pages on the Stewart-Warner and Janitrol combustion heaters; a description of the Minneapolis-Honeywell cabin temperature control system in the D.C.4; and a chapter on metal bellows for pressure detectors and indicators. The material is largely a recapitulation of the respective manufacturers' technical literature and, as such, is useful for reference, particularly as many of the maker's illustrations have been reproduced.

The third book, unlike the other two, sticks to one comparatively limited aspect of the subject, but thoroughly covers the range of air compressors for many duties. The book does not, of course, deal with airborne compressors, but is confined to a severely practical study of their use in the factory. A well-written text, ably amplified by excellent line drawings and photographs, serves to describe the problems of installing the various types of air system that have become indispensable in the modern factory.

Aircraft Designer's Data Book. By Leslie E. Neville. [McGraw-Hill. 85s.]

In his introduction, the author of this book explains that the American technical press has always suffered severely from the geographical concentration of the American aviation industry on the eastern and western seaboard. He it was, while editor of *Aviation*, who started in 1929 the series of design detail sketches that eventually became, after many vicissitudes, *Aviation's Sketchbook*. Firmly convinced of the supremacy of the perspective sketch as a medium for conveying technical information concisely and without ambiguity, the author continued to develop this work despite the high cost that was so greatly enhanced by travel difficulties.

The present volume is a selection from previously published material. Although we would like to commend it highly, for we are in complete accord with the author's views, we must say that it is much more a scrapbook than a data book. Although the material in its 530 large quarto pages has been grouped under component headings it is, nevertheless, a somewhat random collection of sketches and notes about a fairly large number of aeroplanes—American, British and German—none of which is very new. It is much the type of collection that any good engineer will accumulate over a period of years in his folder of cuttings from the aeronautical press. In fact, looking through it, we could not help feeling what a useful book we could make up from the files of AIRCRAFT ENGINEERING! Perhaps the best part of the book consists of the photographs and drawings, both perspective and engineering, of different mechanisms, such as undercarriages, and the wing structural drawings. This book, although very expensive, would be a useful addition to any aircraft manufacturer's reference library.

J. H. S.

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.

Cams and Springs for Poppet Valves. W. H. Lee. Paper bound, 42 pages, illustrated. [Emmott & Co. Ltd., 31 King Street West, Manchester, 3.]

Your Future in Aircraft Engineering. Booklet, illustrated. [S.B.A.C., 32 Savile Row, W.1. Free.]

The Forty-third Annual Report of the Governing Body of the Imperial College of Science and Technology. Booklet. [Imperial College of Science and Technology, Prince Consort Road, S.W.7. Free.]

Mechanical World Electrical Year Book 1951. 357 pages, illustrated. [Emmott & Co. Ltd., 31 King Street West, Manchester, 3.]

American Aviation World-Wide Directory, Autumn, 1950. Paper bound, 651 pages. [American Aviation Publications Inc., 1025 Vermont Avenue, N.W., Washington 5, D.C., U.S.A.]

Instructional Courses

Particulars of Special Courses to be Given by Various Bodies during the Year

Synthetic Resin Adhesives

A 5-day course on Synthetic Resin Adhesives is being arranged at Cambridge from Sunday, September 23, to Saturday, September 29, 1951. Two alternative series of lectures will be given on (1) their use in the wood-working industries, and (2) their application to engineering, electrical manufacturing and other industries, though some of the lectures will be common to both courses.

The fee for the course is £10 10s. inclusive of accommodation in St Catharine's College, meals and transport. Applications for enrolment should be made to Aero Research Ltd., Duxford, Cambridge.

Aeronautical and Electrical Engineering

To meet the growing demand for men trained both in aeronautical and in electrical engineering, the College of Aeronautics, of Cranfield, Bletchley, Bucks, is extending the present electrical section, and is introducing a combined two-year course in these subjects, starting in October, 1951, and with a yearly intake thereafter.

The aim is to give students a grounding in aeronautical engineering in general, together with a more specialist training in those branches of electrical engineering which find application in the aeronautical field.

In the first year of the two-year course, the student will attend selected lectures and laboratories in all the main departments of the College—Aerodynamics, Aircraft Design, Aircraft Propulsion, and Economics and Production—to obtain that insight into these fields of work which is very necessary when applying his electrical knowledge in the service of aeronautics. The electrical training in the first year comes under five main headings:

Applied Electronics

This initially covers the fundamental principles of electricity (including thermionics), and goes on to deal with the increasingly important field of the application of electrical and electronic techniques in the measurement of physical and mechanical quantities.

Communication

This covers the general principles of the transmission of information to and from aircraft with a discussion of the various types of information to be dealt with, and descriptions of practical radio and radar equipments. It is not intended that this should enable the student subsequently to design such equipments, but rather that he should be able to assist the aircraft designer to make the best use of them, and should give the designer of the equipments advice on the aeronautical problems involved.

Aircraft Electrical Systems

The general problem of the supply, storage and utilization of electric power in aircraft is covered. This part of the course also deals with the installation problems of all classes of electrical equipment.

Servomechanisms

Under this heading come all forms of automatic control system, including power-operated flying controls, automatic pilots, etc. Fundamental theory is treated in some detail, and is followed by examples of current practice.

Aerials

In view of the increasing need with high-speed aircraft to suppress aerials inside the aircraft skin, the fundamental theory of aerials is treated in detail. This is followed by an introduction to the problems involved in suppressing all forms of aircraft aerial.

In the second year the foregoing subjects are continued, but the student is allowed a greater latitude in selecting for deeper study those which particularly interest him. In addition each student undertakes work on some research or development problem to form the subject of a thesis.

The course leads to the diploma of the College, which is awarded on the student's progress throughout the two years, and on the quality of the thesis submitted.

The College is of course already well equipped for teaching in Aeronautical Engineering. The present Electrical Section is being expanded to provide the facilities necessary for the new course. In addition to lecture rooms and an efficient workshop, there are five laboratories, and good drawing office facilities. Some of the laboratories border on the airfield which provides an excellent open site for work on aerials and radiation. One of the College aircraft is specially equipped with radio and radar devices for demonstrations in the air; in addition there is a ground demonstration room containing up-to-date radar and other navigation aids.

Students on entry should have a Degree or Higher National Certificate in Mechanical or Electrical Engineering or a Degree in Physics; in addition, the College may admit, after interview, applicants without these qualifications who are judged of equivalent educational standard.

It is hoped that trained students leaving the College will be of great value in the guided missile field, will serve the industry as a valuable link between the designers and manufacturers of aircraft and those responsible for the instruments and devices that are fitted in them; and be able to give help in air traffic control problems.

Production, Technology and Management

The Institution of Production Engineers of 36 Portman Square, W.1, announces that it will be holding its Second Annual Summer School of Production Engineering at University College, Durham, from August 29 to September 2, 1951, when lectures and addresses will be given on Standards of Industrial Performance, Product Design, Materials Handling, Science and Industry, the Armed Services and Industry and Education and Industry. The inclusive charge for the course, including accommodation, meals and gratuities and a copy of the proceedings, is £5 10s., a remittance for which should be sent to the Institution as soon as possible.

Gas Turbine Technology

The School of Gas Turbine Technology, Farnborough Place, Farnborough, Hants, announces the following programme of courses for 1951, applications to attend which should be made to the Principal.

Course No.	Type of Course	Date
35	International Course on Aero and Industrial Gas Turbines (3 weeks)	May 29-June 15
36	Aero Engine Design (2 weeks)	June 24-July 6
37	Design and Applications of Industrial Gas Turbines (3 weeks)	July 15-Aug. 3
38	Aero Engine Design (2 weeks)	Aug. 19-31
39	International Course on Aero and Industrial Gas Turbines (3 weeks)	Sept. 16-Oct. 5
40	Practical Aero Engine Course (2 weeks)	Oct. 8-19
41	Design and Applications of Industrial Gas Turbines (3 weeks)	Oct. 28-Nov. 16
42	Aero Engine Design (2 weeks)	Nov. 25-Dec. 7

A.R.B. NOTICES

British Civil Airworthiness Requirements

The Council of the Air Registration Board announce the issue of the following amendments to British Civil Airworthiness Requirements, which should be inserted in the folder in place of the previous issues.

Contents, Issue 16

General Foreword, Issue 12

Section C, Engines and Propellers, Issue 2

Section D, Aeroplanes, Issue 2

SPECIFICATIONS. Revision of Subsection H10 is necessary as a result of changes to the emergency alighting accelerations specified in D3-8. Because this was the only specification to be issued in Section H, and because the anticipated need for a complete section dealing with specifications peculiar to the Requirements has not materialized, the subsection is being withdrawn from the Requirements and the use of Section H 'Specifications' is to be discontinued. The material hitherto contained in H10 is being revised and republished in leaflet form; copies of this leaflet may be obtained on request.

The Council of the Air Registration Board announce the following amendments to British Civil Airworthiness Requirements under date April 1, 1951:

Contents, Issue 17. General Foreword, Issue 13. Supplement to Section A, comprising—Chapter A3-4, Radio Apparatus; Chapter A3-5, Aircraft Radio Stations.

Remove from the folder and file the following: Contents, Issue 16. General Foreword, Issue 12. Subsections R1 and R2, and Appendices, which are replaced by Chapters A3-4 and A3-5.

Radio Requirements. Now that the requirements relating to the procedure for the approval of radio apparatus and aircraft radio stations have been transferred to the Procedures Section, it is proposed, in the near future, to amalgamate Subsections R3 to R12 into a revised Section R in booklet form. Amendments necessary to bring these requirements up to date are now being made.

Notices to Licensed Aircraft Engineers and to Owners of Civil Aircraft

The Council of the Board announces the issue of the undermentioned:

Notice No. 6, Issue 11. January 1, 1951. British Civil Airworthiness Requirements. General Information.

Notice No. 7, Issue No. 13. January 1, 1951. British Civil Airworthiness Requirements. Particulars of Sections and Subsections issued.

TRADE REVIEWS

D.M.E. Distance Measuring Equipment.

[Ferranti Ltd., Crewe Toll, Edinburgh.]

A concise, clearly-written leaflet that sets out the particulars of the radar navigational aid designed by Ferranti to meet I.C.A.O. development specification (Annex 10 of the Convention) and British Civil Airworthiness Requirements. The system is an interrogator-responder that operates in the 1,000 megacycles/sec. frequency band. The pilot is provided with accurate and continual visual information on distance and homing to a selected ground beacon. The equipment consists of an easily transportable ground beacon set and aerial; the airborne components being a receiver, transmitter and tuning units, a control unit and a distance/homing meter that gives visual indication.

Servicing Instruction: Compressors Type SH6/2A, SH6/5B, SH6/7B, SH6/9.

[The Hymatic Engineering Co. Ltd., Redditch, Worcs.]

These servicing notes, which are graphically illustrated with exploded views and assembly drawings of parts, give complete descriptions of the compressors, together with servicing and overhaul notes and tabular data of fits and clearance. Apart from the absence of pump performance data, all possible particulars are included, so that the notes serve as a more comprehensive description than do most catalogues.

Tools for the Workshop

A Selection of Notes on Recent Equipment and New and Well-tried Methods and Materials

New Euco Micrometer Spacing Collars

When the Euco Ground Thread Micrometer Spacing Collars were introduced a few years ago, the only sizes produced were for 1 in. and 1½ in. arbors and the minimum width ⅜ in. A few months later, the company extended the range to cover 1½ in. dia. arbors and introduced a narrow type micrometer spacer having a minimum width of ¼ in., also available for arbors up to 1½ in. dia. Continental inquiries resulted in the range being extended to cover 16 mm., 22 mm., 27 mm., 32 mm., 40 mm., 55 mm. and 60 mm. with metric calibrations 0.01 mm. As many foreign industrial concerns were using British and American machines, a further demand developed for the English sizes with metric readings, so the range was again extended.

The company is now also manufacturing micrometer spacers for 2 in., 3 in. and 4 in. dia. arbors. The minimum width of these extra large sizes varies from ⅜ in. for the 2 in. dia. arbor, to 1¼ in. for the 4 in. dia. arbor.

The future programme is to continue the manufacture of the popular ¼ in. wide micrometer spacer for arbors up to 1½ in. dia. and to replace the ⅜ in. wide model by a new type with a minimum width of ⅞ in., also available for arbor diameters up to 1½ in.

FIG. 1 shows the new Euco micrometer spacing set for the three standard English and American arbor sizes of 1 in., 1½ in. and 1½ in. expressly designed for the setting up of milling machines.

When two or more cutters require assembling on a milling machine, the usual method is to use solid collars between cutters to give the exact dimensions needed, the assembly then being clamped and a trial cut made. Theoretically the machined dimensions should, of course, coincide with the precise spacing of the cutters, but due to discrepancies that may exist on the teeth of the cutters, or accumulated error on the widths of the various collars employed, or perhaps a slight distortion on the arbor, a trial cut may reveal an error in one or more positions dependent on the machining limits imposed. Consequently, it becomes

necessary to dismantle the arbor by removal of steadies, collars, shims and cutters, in order to re-set with slightly different size collars and shims in an effort to eliminate the errors. Even when the machine produces correctly the whole procedure must be repeated on each occasion that wear on one or more of the cutters takes place.

This new micrometer spacing set removes the necessity for constantly disturbing the set up, by affording means accurately to control the various spacing dimensions without dismantling. This is accomplished by always using the micrometer spacer in conjunction with the standard solid collars when preparing the set up. For instance, for a spacing dimension of ⅜ in. the setter would use a standard collar ⅜ in. wide and set the micrometer spacer to give the balance, i.e. ⅜ in., at the same time making adjustment for machining limits. Subsequent errors due to worn cutters, or other causes, can be immediately corrected by simply slacking off the arbor locknut and turning the calibrated sleeve of the micrometer spacer. This sleeve is machine divided in steps of 0.0005 in. and, as the clearly cut engraved lines are comfortably open, being approximately ⅛ in. apart, close adjustments may be carried out with ease, even to limits as fine as 0.00025 in.

The micrometer spacing set in FIG. 1 is claimed to be the only one of its type in the world. It includes a supply of steel shims from 0.002 in. to ⅛ in. in width, a progressive range of hardened and ground steel collars from ⅛ in. to 1 in. in width, together with the essential micrometer spacer made from special tool steel, hardened and ground throughout, including the internal and external micrometer threads, which are produced on modern thread grinding machines.

The manufacturers are often asked about the possibility of micrometer threads collapsing under the pressure used in clamping the cutters on the milling machine arbor. Many engineers probably envisage a muscled mechanic wielding a 15 in. spanner and a heavy hammer in his endeavours to tighten up the arbor assembly. In order to dispel any doubts in this connexion the following formula relating to the

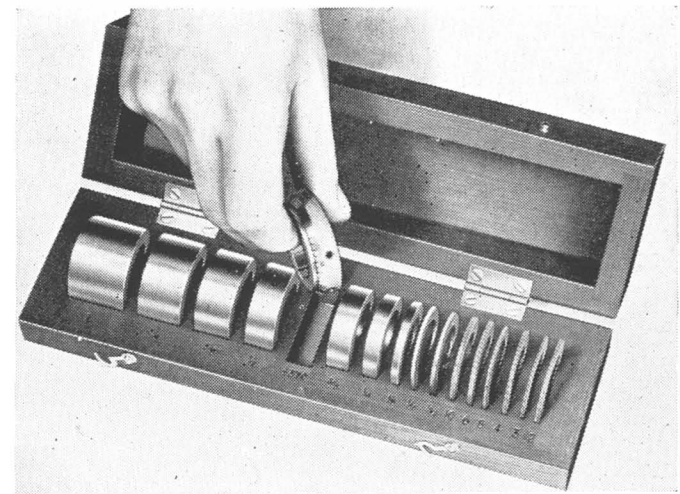


Fig. 1.—The Euco Micrometer Spacing Set

strength of screw thread is worth noting. Resistance of threads to shear is given by $\pi N(Dm+2L)(P-2r \sin 62\frac{1}{2}^\circ)$ ft.

In the case of the micrometer spacer for a 1 in. dia. arbor

N = number of threads in engagement = 10
 Dm = minor diameter = 1.28 in.
 L = $r - (r \cos 62\frac{1}{2}^\circ)$ = 0.00185 in.
 r = radius of thread = 0.00343 in.
 P = pitch = 0.025 in.
 ft = tensile strength of material = 291,200 lb.

Evaluation of the above makes it apparent, that several tons pressure would need to be employed, in which event, the weakest part of the arbor would snap first.

The sets are available in the following sizes listed below:

Set No.	Bore (in.)	Micrometer Width (in.)	Price £ s. d.
A.100	1	$\frac{7}{16}$	5 15 0
A.125	1¼	$\frac{7}{16}$	6 9 0
A.150	1½	$\frac{7}{16}$	7 5 0
S.100	1	$\frac{1}{4}$	5 5 0
S.125	1¼	$\frac{1}{4}$	5 19 0
S.150	1½	$\frac{1}{4}$	6 15 0

Particulars of the full range of this equipment can be obtained from the makers, Euco Tools Ltd., 44 London Rd., Kingston-on-Thames, Surrey.

British Standard Specifications

Copies of the following specifications may be obtained from the BRITISH STANDARDS INSTITUTION, Sales Department, 24 Victoria Street, London, S.W.1, at the prices indicated

B.S. SP. 22-27: 1950. B.A. Washers for Aircraft Purposes.

British Standards for B.A. washers for aircraft purposes have been published by the British Standards Institution. These British Standards apply to washers primarily intended for use with screws (2 B.A. and smaller) used in aircraft instruments, and in electrical and similar equipment for aircraft. The washers are identical with those covered by the revision of B.S. 57—'B.A. bolts, screws, nuts and washers', now in course of preparation, with the exception of provisions relating to protective treatment and identification.

Price 1s. post free.

S.B. 1651: 1950.—Industrial Safety Gloves.

This standard deals with safety gloves, mittens and hand-guards for protection against common hazards in all industries. It is based on practical trials lasting several years and is designed to canalize the demand for safety gloves from more than two hundred different types now commonly supplied, each type in several sizes, into a range of seventeen preferred types, each supplied in a minimum range of sizes. This standardization will facilitate economic production as well as the ordering and stocking of safety gloves. The gloves specified are designed to provide adequate protection, but also to overcome weak points existing in the past and thus to provide the greatest possible economy in use.

The gloves fall into five groups: leather, plastics,

rubber, felt and cotton. The standard includes a list of hazards and recommends the appropriate types of gloves for each hazard. Requirements are given for materials, sizes, manufactures and methods of test; recommendations on the storage and preservation of rubber gloves are included, and a note on the information to be given when ordering gloves.

Price 4s. post free.

B.S. 1686.—Long-period high-sensitivity tensile creep testing.

B.S. 1687.—Medium-sensitivity tensile creep testing.

B.S. 1688.—Determination of time to rupture under stress with or without measurement of creep strain.

The increasing use of metals at high temperatures during recent years has made it essential that satisfactory information should be available about the behaviour of metals at these temperatures. This has automatically given rise to a considerable increase in creep testing, and has in its turn shown the need for standard methods and equipment in order that proper comparisons may be made and correct interpretations given to the tests made by different authorities.

The standards originated in specifications that had been prepared specially to meet the needs of the aircraft industry and it had been originally intended that they should be published in the series of British Standards for aircraft materials and components; but it became clear that the field of application was so wide that the restriction of the standards to this

series was not justified and accordingly they have been published in the general series of British Standards.

Price 2s. each, post free.

B.S. G.126. Electric Power Metal Rectifiers for Aircraft.

Details the requirements for rectifier equipment, rectifier stack assemblies, and rectifier stacks, for rectifying aircraft main and auxiliary A.C. power supplies to D.C.

Price 1s.

B.S. 18: 1950. Tensile Testing of Metals.

This is the fourth revision of the standard which was first published in 1904. With the exception of the definition of proof stress, the standard has not been fundamentally altered. The definition of proof stress now adopted is, however, quite different from that contained in previous issues, as it has been amended to bring it in line with the practice, current in industry, of obtaining proof stress under load.

The definition is amplified to indicate methods which may be used to ascertain if the material is satisfactory when the actual value of the proof stress is not required.

Section 1 of the Standard contains the definitions of the principal terms relating to the tensile strength of materials. Section 2 sets out in detail the forms of standard tensile test pieces for sheets, strips, sections, machined and unmachined rods and bars and so on. It also includes the special test pieces for cast-iron, malleable cast iron, steel tubes, cylinders and wire. Section 3 deals with the standard methods of procedure for tensile testing, and includes guidance on the preparation of the test piece for testing.

Price 2s. 6d. post free.

B.S. G.125: 1950. Turn and Slip Indicators for Aircraft Purposes.

Covers instruments calibrated for nominal air speeds of 140 and 280 knots.

Price 1s. post free.

Trade Announcements

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

Arc Welding Film

The Quari-Arc Company Limited of Bilston, Staffs., announce the completion of an instructional film on arc welding, which runs for 20 minutes and is 16 mm. sound and printed in Kodachrome colour. It shows the way in which a weld is made and principles to be followed in producing good welds. Copies are available free of charge on application to the Company and arrangements can be made for the hire of sound projector and operators if desired.

B.E.A.C. Chairman

The Minister of Civil Aviation has extended the term of appointment of Lord Douglas of Kirtleside as Chairman of British European Airways Corporation until March 13, 1954. His original appointment, dated March 14, 1949, was for three years, and his term has thus been extended to cover a five-year period. The Chairman of B.O.A.C. holds his office for a similar term.

The Birmingham Small Arms Company Limited

Mr James Leek, C.B.E., Mr James Maclaren (Managing Director of B.S.A. Tools Ltd.), and Mr J. Sangster have been elected Directors of the Birmingham Small Arms Company Limited.

The Company also announces that it has acquired the share capital of the Triumph Engineering Company Limited, the Management of which will be conducted by its own Board of Directors.

College of Aeronautics—New Principal

The Governors of the College of Aeronautics, Cranfield, Bedfordshire, announce the appointment of Air Marshal Sir Victor Goddard, K.C.B., C.B.E., M.A., who lately retired from the post of Air Member for Technical Services, to succeed Mr E. F. Relf, C.B.E., A.R.C.S., F.R.Ae.S., F.R.S., as Principal of the College. Air Marshal Sir Victor Goddard will take up his duties on September 1, 1951.

New Director of Hawker Aircraft

Mr Edward H. Jefferson has been named a Director of Hawker Aircraft Limited, of Kingston-on-Thames, Surrey, a member company of the Hawker Siddeley Group.

Mr Jefferson has been with Hawker Aircraft for 30 years. His first job was in the inspection department. In 1922 he became the Company's only inspector and rose to be Chief Inspector from 1938-1947.

He was appointed Quality Controller in 1947, which post he will continue to hold in his new capacity.

Mond Nickel Fellowships

The Mond Nickel Fellowships Committee now invites applications for five Fellowships of average value of £750 each for 1951. Fellowships will be awarded to selected candidates of British nationality with degree or equivalent qualifications, to enable them to obtain wider experience and additional training in industrial establishments, at home or abroad, to make them more suitable for future employment in senior technical and administrative positions in British Metallurgical Industries. Each Fellowship will cover one full working year. Applicants will be required to state details of the programme they wish to carry out. Particulars and form of application are available from the Secretary, Mond Nickel Fellowships Committee, 4 Grosvenor Gardens, London, S.W.1. Completed application forms are required by June 1, 1951.

Normalair Limited

Owing to the increasing scope and activities of the Normalair Ltd. of Yeovil, additional plant and equipment is being installed to enlarge the capacity for dealing with development and production work.

The following appointments have been made: Mr E. C. Wheeldon, Managing Director; Mr W. M. Widgery, a Director and Chief Engineer; Comdr F. W. N. Bassett, a Director and Commercial Manager; the Hon Charles M. McLaren, a Director; Mr C. T. Jones, Secretary.

A. C. Wickman—New Area Manager, Birmingham Office

Mr George Kelway has been appointed Area Manager in Birmingham in succession to Mr C. R. Perks, who is leaving England shortly to establish and manage a new A. C. Wickman branch factory at Mentone, Melbourne, Australia.

Mr Kelway has been with the company since 1932, and for the past five years has specialized in machine tool sales in the London area. He is an ex-apprentice of Alfred Herbert Ltd., and has been employed successively with English Electric Company of Rugby and B.S.A. Tools of Birmingham, prior to joining A. C. Wickman. During the war he was loaned by the company to the Ministry of Supply, Machine Tool Control as Technical Adviser.

Wood Preservation Conference

The British Wood Preserving Association is holding a Convention at Cambridge from June 25-27, 1951, with headquarters at Gonville and Caius College.

A number of papers related to various aspects of wood preservation are being contributed by authorities overseas and in this country, and these will be discussed on June 26 and 27.

Further particulars may be obtained from the Secretary, British Wood Preserving Association, 21 College Hill, London, E.C.4.

E. D. Wynn's Move

E. D. Wynn & Co., stockists of aircraft instruments and electrical accessories, announce that they have acquired more modern premises on Staverton aerodrome, which include a fully equipped modern aircraft instrument laboratory and bonded store.

The new postal address, as from March 27, 1951, is E. D. Wynn & Co., Staverton Aerodrome, Cheltenham Road, Gloucester. Telephone, Churchdown 3264 (3 lines); telegraphic address, 'Wynn, Gloucester.'

New R.Ae.S. President

Major F. B. Halford, C.B.E., F.R.Ae.S., Vice-President, has been elected President of the Royal Aeronautical Society for the year 1951-1952, and will take office on May 10, 1951, at the annual general meeting.

Shell-Mex Managing Director

Mr C. M. Merrick, Managing Director of Shell-Mex and B.P. Ltd., Shell-Mex House, Strand, W.C.2, has retired. He is succeeded by Mr C. M. Vignoles, O.B.E.

Silentbloc in Australia

Silentbloc flexible bearings, anti-vibration mountings and flexible couplings are to be made in Australia.

Mr P. J. de Steiger, B.E.E., M.Mech.E., A.M.I.E. (Aust.), A.F.A.I.M., who spent 1950 in England studying the manufacture and application of Silentbloc products, has been appointed Technical Manager.

Silentbloc (Australia) Pty. Ltd., is jointly owned by Leggett Products Pty. Ltd., Melbourne, manufacturers of engineering rubber, and Silentbloc Ltd., Victoria Gardens, Ladbroke Road, W.11. Their address is Doonside Street, Richmond, E.1, Victoria.

Smart & Brown Machine Tools

Smart & Brown (Machine Tools) Ltd., of 24-25 Manchester Square, London, W.1 (Works: Sabel Works, London Road, Biggleswade, Beds) announce that they are in no way connected with Smart & Brown (Engineers) Limited, which has recently been acquired by Thorn Electrical Industries Ltd., of 105 Judd Street, London, W.C.1.

Trinity Designs & Methods Limited

The formation is announced of a new company known as Trinity Designs & Methods Ltd., at Grosvenor Gardens House, Grosvenor Gardens, S.W.1. Trinity Designs & Methods Ltd., are technical consultants, tool designers and method engineers, and are already responsible for the design of a number of intricate tool sets for well-known manufacturing concerns.

TRADE PUBLICATIONS RECEIVED

Twenty Years of Progress

[British Institute of Engineering Technology, Shakespeare House, Stratford Place, W.1]

Ediswan Microfilm Readers

[The Edison Swan Electric Co. Ltd., 155 Charing Cross Road, W.C.2]

Metalastik Bush Catalogue, 1950

[Metalastik Ltd., Evington Valley Road, Leicester]

Fox Steels

[The United Steel Companies Ltd., 17 Westbourne Road, Sheffield, 10]

Dunlop Developments for the Aircraft Industry

[Dunlop Rubber Co. Ltd., St James's House, St James's Street, S.W.1]

'Antisep' All-Purpose Base

[Edgar Vaughan & Co. Ltd., Legge Street, Birmingham, 4]

Rotax CT0101 Gas Turbine Starter

[Rotax Ltd., Willesden Junction, N.W.10]

Drying Ovens

[Funditor Ltd., 3 Woodbridge Street, E.C.1]

Cold Pressure Welding

[The General Electric Co. Ltd., Magnet House, Kingsway, W.C.2]

Facts About Degreasing

[Basol Ltd., 16 Bolton Street, Piccadilly, W.1]

Aero Research Technical Notes

Bulletin No. 97. Veneering with Aerolite K
[Aero Research Ltd., Duxford, Cambridge]

'Planocop' Document Copying Developer

'Cobrol' Bromide Paper Developer
[May & Baker Ltd., Dagenham]

E. H. J. 12½ ton Unit Press

[E. H. Jones (Machine Tools) Ltd., Garantools House, Portslade, Sussex]

D.M.E. Distance Measuring Equipment

[Ferranti Ltd., Hollinwood, Lancs.]

The Use of Aluminium Alloys in Structural Engineering

[The Aluminium Development Association, 33 Grosvenor Street, W.1]

Vickers Overseas News. Winter 1950-51—The Choice of a Wind Tunnel

[Vickers Ltd., Broadway, Westminster, S.W.1]

The Acru Finger Tools

[The Acru Electric Tool Manufacturing Co. Ltd., 123 Hyde Road, Ardwick, Manchester, 12]

The Development of Technological Education for Production Engineers

[The Institution of Production Engineers, 36 Portman Square, W.1]

Gear Shaving Cutters

[David Brown (Huddersfield) Ltd., Park Gear Works, Huddersfield]

Miniature Ball Bearings. Mounting Bulletin No. 1

[Miniature Bearings Ltd., 192 Sloane Street, S.W.1]

Elastomeric Engineering Examples

[Andre Rubber Co. Ltd., Kingston By-Pass, Surbiton]

B.S.A. Acme-Gridley Six-Spindle Automatic Bar Machine

[B.S.A. Tools Ltd., Mackadown Lane, Marston Green, Birmingham]

Aero Research Technical Notes

Bulletin No. 98. Bonding of Rubber to Metal
[Aero Research Ltd., Duxford, Cambridge]

Matling 'Palatrucs' and 'Palastaca'

[Matling Ltd., 14 Ossington Street, W.2]

The Modern Way: The Westland Sikorsky S-51 Helicopter

[Westland Aircraft Ltd., Yeovil, Somerset]

'Marlco' Two-Speed Press

[W. H. Marley & Co. Ltd., 105 High Road, Southgate, N.11]

'Avica' Stainless Steel Flexible Pipe Assemblies

[Avica Equipment Ltd., 50 Pall Mall, S.W.1]

Bakelite Progress, Winter 1950-51

[Bakelite Ltd., 12 Hobart Place, S.W.1]

Thermal Insulation

Working with Onazote
[Expanded Rubber Co. Ltd., 675 Mitcham Road, Croydon]

Research in Industry

[Tiltman Langley Laboratories Ltd., Redhill Aerodrome, Surrey]

The College of Aeronautics

[The College of Aeronautics, Cranfield, Bedfordshire]

The Brush-Aboe Group Commonwealth Scholarship Scheme

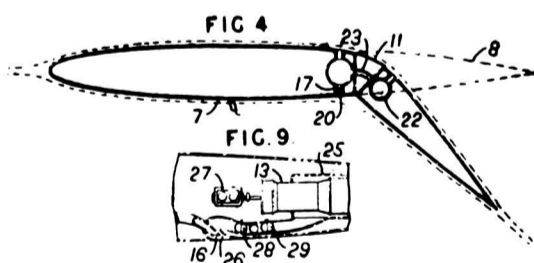
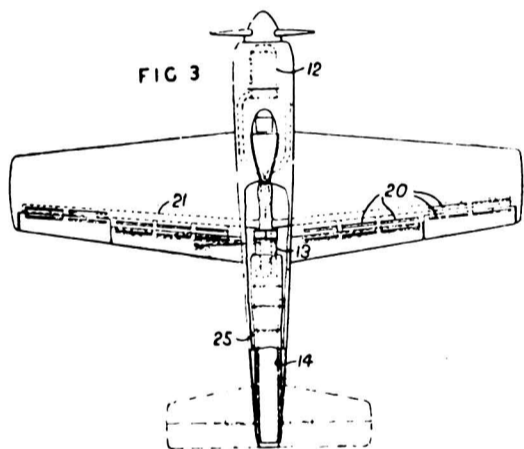
[The Brush Electrical Engineering Co. Ltd., Loughborough]

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.

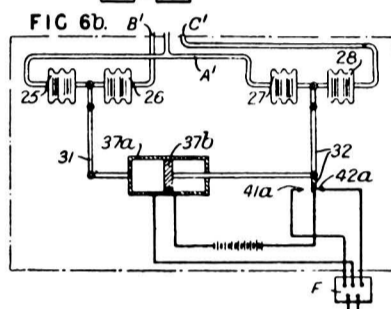
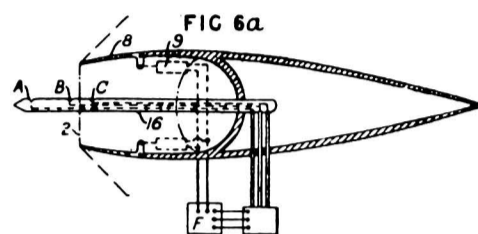
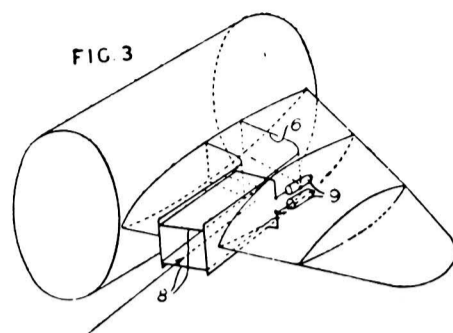
607,457. Boundary layer control. Goodyear Aircraft Corporation. Feb. 5, 1946, No. 3590. Convention date, Feb. 10, 1945. (Class 4.) (Also in Group XXVI.)

An aircraft is provided with a jet engine with a nozzle terminating at the rear of the fuselage, a casing spaced from and surrounding the jet tube for substantially its full length forming a suction pump operated by the exhaust gases being connected to slots in the wings for promoting boundary layer suction. The aircraft illustrated is provided with an internal-combustion engine 12 driving a propeller in addition to the gas turbine 13, the exhaust of which discharges through the jet tube 14. The turbine and tube are enclosed in a casing 25 provided with a forward extension 26 into which is led the exhaust pipe 16 of the engine 12. Boundary layer air is drawn through slots 20 in the surfaces of the wings, ailerons and flaps into conduits 21 connected with the casing 25, the necessary suction being provided by the exhaust from the turbine and/or the engine 12, under the control of valves 28, 29. The turbine and jet tube are cooled by the air flowing between the casings 14 and 25. The starter motor 27 may be used in the event of failure of the turbine to promote sufficient suction to remove the boundary layer. The ailerons or flaps 8, FIG. 4, are hinged to the lower surfaces of the wings 7, the gaps in the upper surfaces being bridged by strips 11 which preserve the aerofoil profile. Ducts 22 communicate with the slots 20 in the ailerons or flaps, and by flexible connections 23 with the main conduits 21. Valves 17 may be provided to control the suction at the lower wing slots.



607,686. Air inlets operating under supersonic velocity conditions. Power Jets (Research and Development), Ltd., and L. J. Cheshire and A. G. Smith. Feb. 1, 1945, No. 2609. (Class 4.) (Also in Group XXXV.)

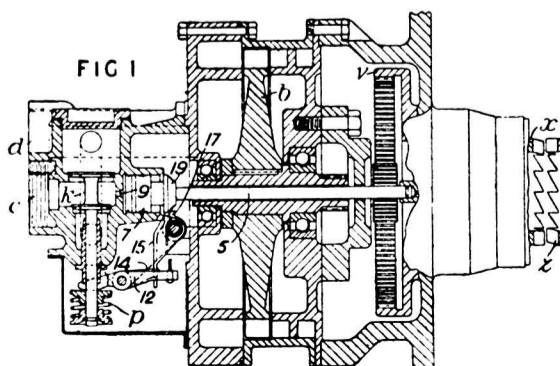
An air inlet for a fluid-flow diffuser system, such as a gas turbine for an aircraft, intended to operate under supersonic velocity conditions and affected by a shock-wave when so operating, is of variable area so that the whole of the air-flow presented to the inlet may be made to pass therethrough, means being provided to indicate variations in a characteristic condition at the inlet and thereby the inlet area adjustment required to ensure that the whole of the airflow will pass through the inlet. In the form shown in FIGS. 3, 6a and 6b, an aircraft wing is formed with an air duct 6, the inlet area of which is adjustable by means of flaps 8 operated by jacks 9. A casing 16 mounted on the axis of the duct is provided with three static pressure heads A, B, C arranged so that under correct operating conditions the shock-wave 2 is located between B and C. Under such conditions the pressures at A and B are equal and less than that at C, while if the wave moves upstream of B the pressure



at that point will rise to the value at C. Pressure gauges may be connected to the points A, B, C and variations in their readings due to movement of the shock-wave utilized by the pilot for the manual control of the jacks 9 to make appropriate adjustments of the area of the air inlet. Preferably, however, the movement of the shock-wave is utilized to effect automatic adjustment of the flaps 8. In the arrangement shown in FIGS. 6a and 6b, the pressure leads A, B, C are connected to pairs of capsules 25, 26 and 27, 28 respectively, the capsules being connected to pivoted members 31, 32 connected to the elements 37a, 37b, and 41a, 42a of electric control switches. Movement of the levers 31, 32 as the result of displacement of the shock-wave actuate the switch elements and a control device F by means of which the flaps 8 are adjusted. Various forms of air inlet are described, of rectangular or circular cross-section and provided with hinged or sliding flaps for varying the area of the inlet opening.

607,897. Turning-gear. Rotax, Ltd., and J. D. S. de Guerin. Feb. 12, 1946, No. 4370. (Class 7 (v).)

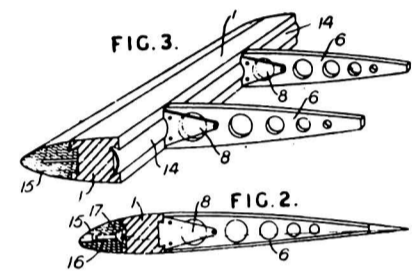
An engine starter using compressed gas comprises a turbine *b* connected by a reduction gear to a clutch member *x* resiliently splined to the last gear member *v*, an inlet *c* connected to the turbine jet nozzles, a piston 7 which is supplied with a restricted flow of gas through orifice 9 so that it engages the members *x* and *z* through the rod 5 after the turbine has been accelerated, a poppet valve *k* which directly connects the inlet *c* with the outlet *d* and which is spring loaded by a spring *p* initially compressed by a Bowden cable operated lever 12 which is held in position by a catch 15 engaging a lever 14 and a ferrule 19 on the rod 5 which when the engine fires and forces, by its cam action on the member *x*, the said ferrule to the position shown, it trips the cam 17 which also trips the



catch 15 and releases the lever 14 so that preloading on the spring *p* is released and the valve *k* opens, so bypassing the gas pressure and stopping the turbine. In a modification, preloading is carried out by an electrical solenoid which has in its energizing circuit a set of contact points which are opened when the turbine reaches a predetermined speed by a further magnet operated by current from a small electric generator on the turbine shaft.

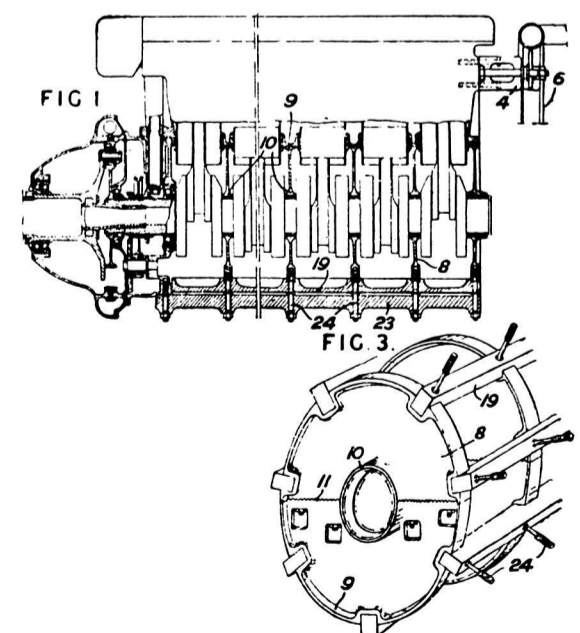
608,458. Helicopter blades. Soc. Nationale de Constructions Aeronautiques du Sud-Est. Feb. 25, 1946, No. 5754. Convention date, Feb. 3, 1942. (Class 4.)

A supporting blade for rotary wings of aeroplanes comprises a central longitudinal main member 1 having its section shaped to form slots and projections for the attachment of rear and front wing components. Rear component 6, FIG. 2, is a rib with dovetailed tongue-and-groove connection with member 1 and is further secured by an attached plate 8 similarly connected to the member 1; front component 15 forms an impact edge member similarly secured and made capable of expansion by means of slot 16 and taper head 17 adjusted by a bolt. The plates 8 for the ribs may also be slotted or shaped to allow for their being to fit the grooves. Spacing members 14, FIG. 3, for the ribs 6 may be sprung into the grooves of member 1. In modifications, the member 1 may be formed with tongues engaging in grooves of the wing components.



608,517. Radial engines. Mathis Soc. Anon. Feb. 25, 1946, No. 5868. Convention date, Nov. 21, 1941. (Class 7, (ii).)

A radial engine is formed of a number of longitudinal cylinder blocks arranged around a crankshaft and supported at their rear ends by a ring 4 attached to the aircraft frame 6, a number of independent steel cheeks 8 interconnected by stay-bars 19 to support said crankshaft and a number of securing members 23, slipped on the studs 24 embedded in the cheeks 8, which but against a shoulder on the cylinder blocks and hold them in place. The cheeks 8 are provided with an external flange 9 which fits in a correspondingly shaped seat in the cylinder block and an internal flange 10 to support the crankshaft bearing, the said cheeks being made in two halves with the diametrical jointing face 11 toothed to prevent lateral movement between the upper and lower components.



SHOCK-WAVE SHADOW PHOTOGRAPHY

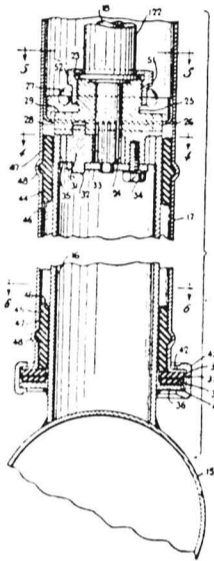
It is regretted that Fig. 15 of the above article, on p. 98 of the April issue, was reversed and appeared upside down.

U.S. Patent Specifications

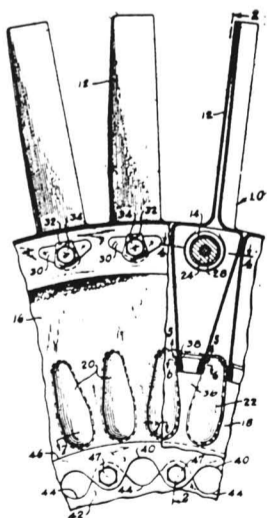
These details and drawings of patents granted in the United States are taken, by permission of the Department of Commerce, from the 'Official Gazette of the United States Patent Office'. Printed copies of the full specifications can be obtained, price 10 cents each, from the Commissioner of Patents, 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.

2,537,650. Steerable Aircraft Undercarriage. Roy W. Brown Akron, Ohio, assignor to The Firestone Tire & Rubber Company, Akron, Ohio, a corporation of Ohio. Application March 7, 1947. Serial No. 733,152 10 Claims. (Cl. 244—50.)

In a steerable aircraft undercarriage a tubular member having a flanged lower end and being adapted to engage with an aircraft, an open centre cup secured to said tubular member at its load receiving end, a housing member slidably received in said cup and engaged thereby to prevent relative rotation therebetween, a flexible shaft having a splined end, means securing said flexible shaft to said housing member with said splined end being positioned therein, a plurality of planetary gears, means journaling said planetary gears in said housing member, a member having an upper end and being adapted to engage with and support an aircraft wheel said wheel support member being telescoped into engagement with said tubular member, an internal gear associated with the upper end of said wheel support member and engaged with said planetary gears for rotation thereby, said housing being abutted against and supported by the upper end of said wheel support member, said wheel support member having a flange on its periphery, a thrust bearing positioned on the flange on said wheel support member, the flange on said tubular member bearing on said thrust bearing so as to support said tubular member thereon for relative rotational movement, and friction bearings positioned between the telescoped sections of said wheel support member and said tubular member to aid in positioning same for relative arcuate movement, said friction bushings having metal backing plates engaged with said tubular member.



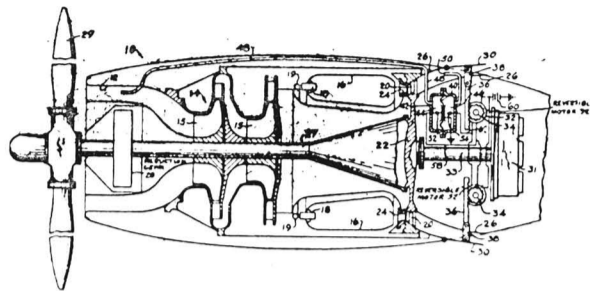
2,537,739. Fan Blade Mounting. Allan Chilton, Ridgewood, N.J., assignor to Wright Aeronautical Corporation, a corporation of New York. Application October 26, 1946. Serial No. 705,988. 6 Claims. (Cl. 170—160.52.)



A vaned rotary blower comprising a pair of disks co-axially secured together, each of said disks having circumferentially spaced depressions, the bottoms of said depressions bulging toward and abutting corresponding depressions in the other of said disks thereby forming tubular spaces radially disposed between said disks and adjacent pairs of said abutting depressions, a plurality of circumferentially spaced vanes having their working portions projecting outwardly beyond said disks, means securing each of said vane to and between said disks for pivotal movement about an axis disposed adjacent the radially outer edges of said disks with the shank of each vane extending inwardly between said disks into one of said tubular spaces, and rubber-like resilient means between each of said vane shank extensions and the walls of its associated tubular spaces.

2,537,772. Turbo-Prop Exhaust Nozzle Control System Utilizing Impact and Exhaust Pressures as Parameters.

Wilton G. Lundquist, Hohokus and Kenneth A. Browne, Ridgewood, N.J. assignors to Wright Aeronautical Corporation, a corporation of New

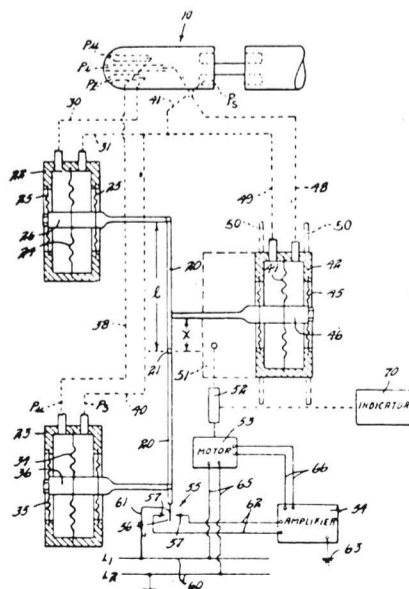


York. Application November 30, 1944. Serial No. 565,980. 9 Claims. (Cl. 60—35.6.)

An aircraft gas turbine power plant having a combustion chamber, a turbine arranged to be driven by combustion gases from said chamber, a compressor drivably connected to said turbine for supplying said chamber with compressed air, a bladed aircraft propeller also drivably connected to said turbine, a forwardly directed air intake duct for said compressor, a rearwardly directed exhaust duct through which the turbine exhaust gases continuously discharge during turbine operation, and an adjustable discharge nozzle for said exhaust duct; means providing a first fluid pressure which is substantially proportional to the impact pressure of the surrounding air relative to the power plant; means providing a second fluid pressure which is substantially proportional to the impact pressure of the exhaust gases discharging through said duct; means responsive to changes in said fluid pressures; and means controlled by said responsive means for adjusting said nozzle so that an increase in said first-mentioned fluid pressure and a decrease in said second-mentioned fluid pressure both tend to effect a closing adjustment of said nozzle.

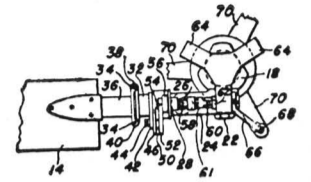
2,537,932. Linear Force Balance Angle of Attack Sensing Device. Waldo H. Kliever, Minneapolis, Minn., assignor to Minneapolis-Honeywell Regulator Company, Minneapolis, Minn., a corporation of Delaware. Application October 11, 1948. Serial No. 53,834. 9 Claims. (Cl. 73—180.)

An angle of attack indicating apparatus for aircraft comprising a sensing head having impact and static pressure orifices and a pair of angle of attack sensing orifices, a first pressure responsive means responsive to the difference between one of said attack angle pressures and said static pressure, a second pressure responsive means responsive to the difference between the other of said attack angle pressures and said static pressure, a lever pivoted at its mid point and having its extremities actuated by pressures from said first and second pressure responsive means, a third pressure responsive means responsive to the difference between impact and static pressures, means including a motor means for directing the response of said third pressure responsive means on said lever and at a variable distance to either side of said pivot depending upon the operation of said motor means, contact means mounted on and actuated by said lever and adapted to control the energization of said motor means from an electrical source, and means for indicating the distance between the point of the response of said third pressure responsive means and said pivot.



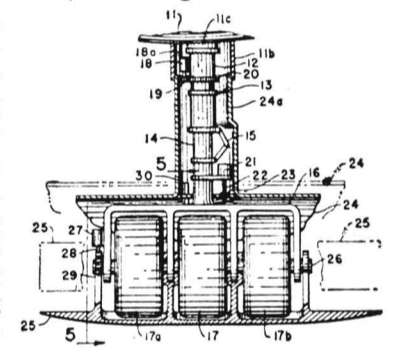
2,538,082. Helicopter Control. Michel D. Buivid, Milford, Conn., assignor to United Aircraft Corporation, East Hartford, Conn., a corporation of Delaware. Original application March 31, 1943, Serial No. 481,254, now Patent No. 2,405,777, dated August 13, 1946. Divided and this application February 12, 1946, Serial No. 647,031. 4 Claims. (Cl. 170—160.25.)

In combination with a rotor blade, a rotor axle, a hub mounted on said axle, a first pivotal connexion adjacent the hub for guiding the blade in its coning angle changes, a second pivotal connexion between said first connexion and said blade for guiding the blade in its oscillations in the plane of rotation of said blade and a third pivotal connexion between the second pivotal connexion and said blade about which said blade is movable to effect changes in pitch of the latter, means for changing the pitch of said blade comprising a shaft connected with said blade for changing the pitch thereof by rotation of said shaft, said shaft having its axis lying substantially in the vertical plane containing the feathering axis of said blade, a bearing for one end of said shaft mounted on said third connexion, a bearing for the other end of said shaft carried by said hub, and means also carried by said axle for rotating said shaft, said shaft including universal joints and a sliding connexion between said bearings whereby said blade may change its coning angle and oscillate in the plane of rotation of said blade without affecting the pitch setting of the latter.



2,538,389. Aircraft Landing Gear. Alvin C. Smith, Columbus, Ohio, assignor to Curtiss-Wright Corporation, a corporation of Delaware. Application November 6, 1948. Serial No. 58,729. 15 Claims. (Cl. 244—103.)

In aircraft, ground-engaging means rotatably supported from the aircraft, an elongated streamlined fairing disposed about said ground-engaging means, the length of said fairing disposed substantially co-directional with a first axis of rotation of said ground-engaging means, and means of rotating said ground-engaging means and said fairing about an axis substantially normal to said first axis of rotation.



In aircraft, horizontally rotatable ground-engaging means, an elongated streamlined fairing concentrically disposed about said ground-engaging means, the length of said fairing disposed substantially co-directional with the axis of rotation of said ground-engaging means, said fairing having an opening through the bottom portion thereof, skid means mounted for rotation about said horizontal axis of rotation of said ground-engaging means, and means for extending said skid means from a retracted position alongside said ground-engaging means and within said fairing to an extended operative position beneath said ground-engaging means and within said fairing opening.

STANDARDS FOR NUTS & BOLTS

B.S. No. A.27: 1950.—Medium Tensile Steel Hexagonal Nuts for Aircraft.

This Standard relates to ordinary, thin, slotted and castle nuts, specifically for use in aircraft.

Price 1s. post free.

B.S. A.30: 1950. High Tensile Steel Close Tolerance Hexagonal Headed Bolts (Machined from Bar or Cold Headed).

This is one of the series of specifications prepared by the British Standards Institution for bolts for aircraft purposes.

Price 1s. post free.

B.S. Nos. S.112, S.113 and S.114: 1950.—Steel Bars for the Manufacture of Aircraft Bolts and Nuts.

S.112 refers to 40 ton semi-free cutting steel; S.113 to 45 ton carbon steel, and S.114 to 55 ton manganese-molybdenum steel.

Price 1s. post free.