ROTODYNE

Fairey's Big Convertiplane Nears Completion: a Detailed Description

IT may be our phlegmatic British temperament or it may be familiarity with the Gyrodyne and the Rotodyne models one has seen at Farnborough and Le Bourget. Whatever the reason, the fact that the Fairey Aviation Company are to fly the very first British convertiplane—a full-scale 40-seater—before the end of the year is not so readily appreciated as an event of this magnitude should rightly be. Moreover, in the writer's personal opinion the configuration of the Rotodyne is by far the most logical and practical yet revealed.

The Principles. The Rotodyne is an extrapolation of the original Gyrodyne principle: power-driven rotor for vertical flight, with propellers for propulsion and autorotating rotor for forward flight. Where the Rotodyne differs from its predecessor is in having a considerable wing to share the lift with the windmilling rotor. The essential principles which led to this particular configuration require to be briefly stated for a proper understanding of the Rotodyne. It was chosen firstly as being the best compromise to give VTOL ability with a practical cruising speed of 160 kt.

The bane of the helicopter designer in search of speed has always been the stalling of the retreating blade, the true airspeed of which is the algebraic sum of the rotational velocity of the rotor and the forward speed of the aircraft. In other words, as aircraft speed rises the true airspeed of the retreating blade falls. Since there are practical limits to blade r.p.m. (imposed by centrifugal loading) and blade area (because of weight and drag) the only palliative for blade-stall is to reduce the loading and thereby the stalling speed of the critical inner portion. In the Rotodyne, at cruising speed, the wing carries 60 per cent of the load.

Again, a propulsive rotor requires more incidence—and is, in any case, a device far removed from optimum efficiency in the horizontal plane, so that propellers are a logical corollary to an "off-loaded" rotor.

Inevitably, a convertiplane must carry dead weight from one form of flight to the other—the wing and tail at take-off, the rotor drive while cruising. In the case of the Rotodyne, however, there is no cumbersome irreversible mechanism for the rotation of wing and/or rotors through ninety degrees, while there is some compensatory saving in the absence of a tail rotor.

A single rotor was chosen by Fairey because of the greater reliability which it confers and because of the shorter time required to prove its reliability to licensing authorities. The tip-jet drive was adopted to simplify the transmission problems of a large rotor by the elimination of torque and gearing—6,000 h.p. gearing in this case. As a "bonus," tip drive also makes drag hinges unnecessary.

Before the present high-pressure jet drive was adopted each of the alternatives was examined. Taking them in descending order of fuel consumption they are: rockets, lowest drag but prohibitive propellant quantities; ramjets, high drag and poor economy; pulsejets, high drag, high fuel consumption and vibration; low-pressure mixed-gas jets, high rotor drag due to large ducts; high-pressure jets, the ultimate choice; and turbojets, best fuel consumption, but high weight and drag plus severe mechanical problems.

The high-pressure jet offered only a fifth or a sixth of the fuel consumption of the ramjet for a much lower drag and could be relatively easily supplied with air from the propulsive engines. Furthermore, with the money-earning part of the flight made in autoration, the high drag of the ramjet would have been a severe penalty.

The pressure jet is, of course, noisy—it is, in effect, an after-burner—but even unsilenced is rather less cacophonous than a ramjet or pulsejet of similar thrust. One imagines that the noise will be of little trouble to the passengers, for it will last only three or four minutes at each end of the flight and, in any case, they are insulated from it. Fairey are, too, doing much work on noise reduction on an *ad hoc* basis. The latest sixteen-slot nozzle makes a reduction of 10 decibels over the plain one, which is equivalent to no more than 10 per cent of the original volume. The main task now, according to Dr. G. S. Hislop (chief designer, helicopters) is to concentrate upon developing this new engine to the pitch of reliability of old-established types.

Airworthiness Aspects. An aspect which is liable to be overlooked is that there are as yet no airworthiness requirements for convertiplanes. Fairey therefore followed the principle which had led to the Rotodyne being designed as a full-scale usable article and not simply as a research aircraft. Such flight research into the general characteristics and handling of the Rotodyne configuration—particularly transition—as was deemed essential has been carried out over the past three years on the converted Jet Gyrodyne.

Design work has been based on *British Civil Airworthiness Requirements, Section G, Helicopters,* and also on fixed-wing requirements for a twin-engined aeroplane of comparable size and performance. The gaps between the two sets of rules have been met by basic thinking on the part of the Fairey design team in an endeavour to meet the likely requirements of the future.

In other words, everything possible is being done to evolve a true commercial vehicle with safety standards in line with current airline practice. An example of the self-inflicted "penalties" which are deemed essential is that at full gross weight a single-engined rate of climb of 150 ft/min will be available with adequate control at 5,000ft, using only cruise power on the remaining engine.

The background to these flight characteristics was laid by a programme involving more tunnel time than has, it is believed, ever been put in on a British rotorcraft. A one-sixth-scale model of the complete aircraft without rotor was tested for over 400 hours in the Fairey 11ft closed-circuit wind tunnel at Hayes to establish all the lift-drag characteristics under fixed-wing conditions. In addition, over 200 hours have been accumulated on a 1/15th-scale model with a 6ft-diameter rotor to investigate the effects of downwash.

This was an extremely difficult task, because it was desired to bring in tilting of the model—60 deg has actually been provided for—and the rotor requires some 20 h.p. Such power could not be transmitted satisfactorily within the dimensions of the model, so the latter is suspended (inverted) from the normal tunnel balance system, while the rotor is driven by a gearbox and transmission system from an electric motor on the floor of the building. Model and rotor head are so mounted that, although they are

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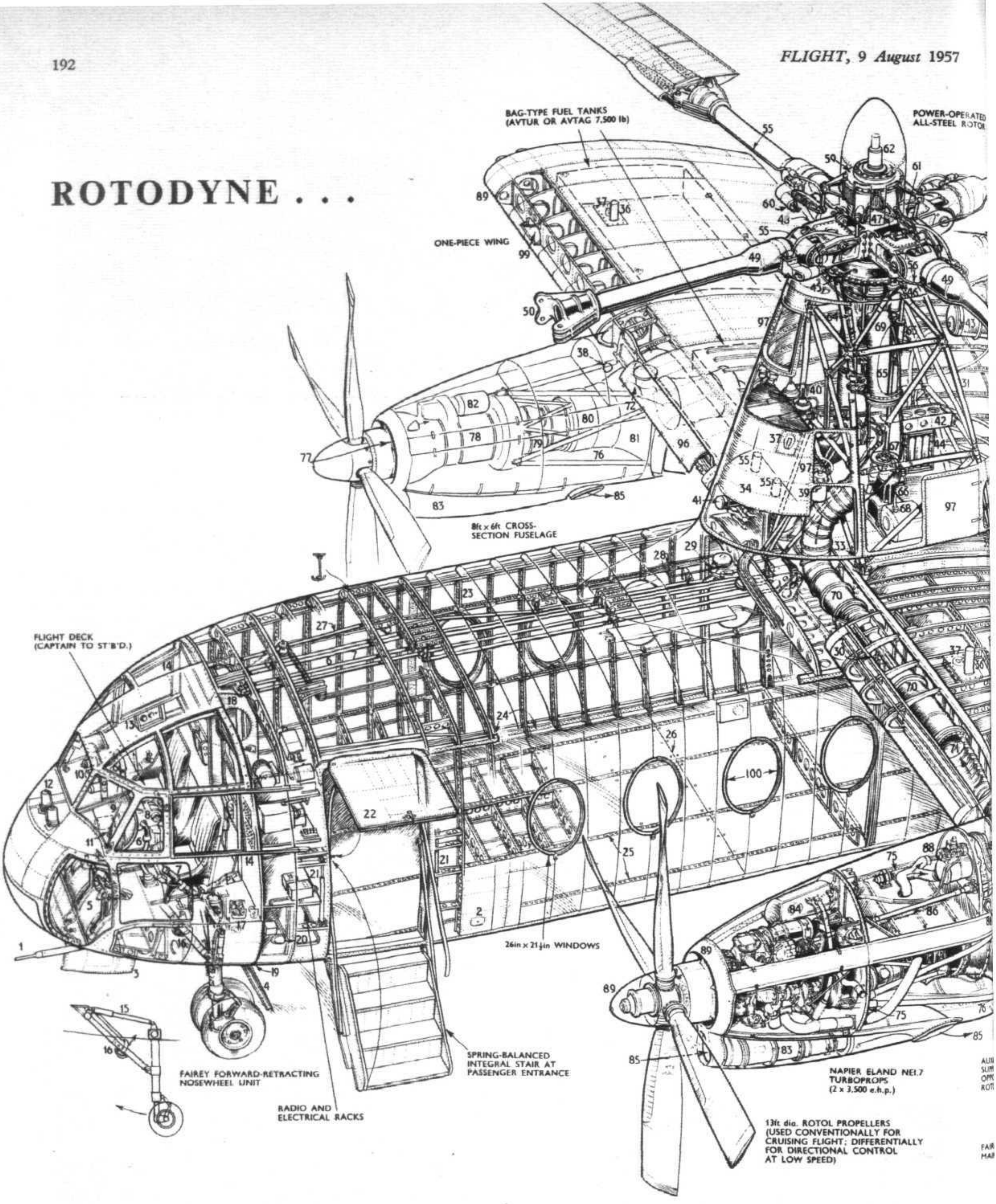
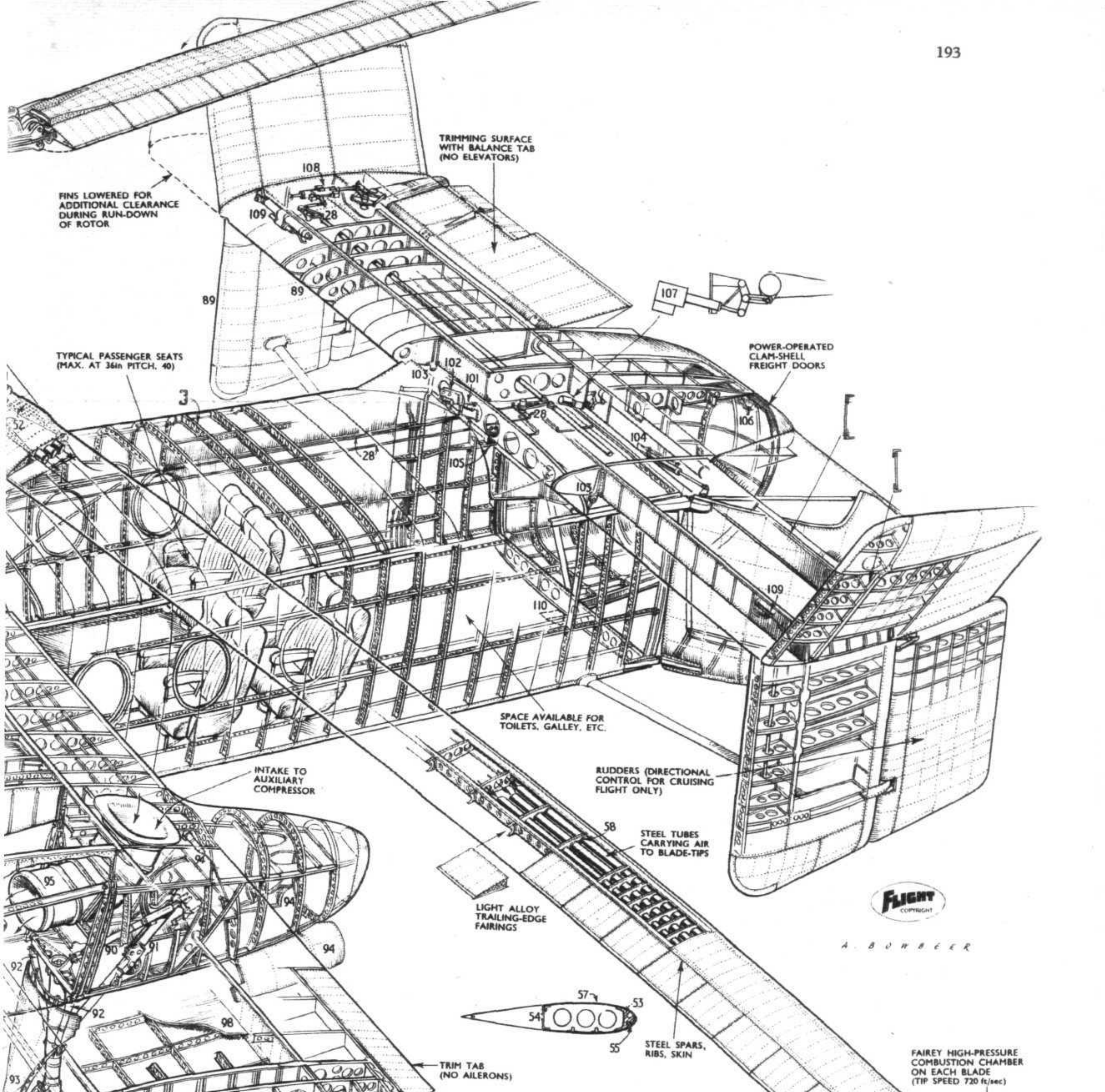


The Rotodyne (two Napier Elands, of 3,500 e.h.p. each, and four Fairy tip-jet units) is designed to carry 40 passengers or 9,000 lb of freight over stage-lengths of up to 300 n.m. This special "Flight" drawing illustrates the structure and details of the first prototype.

1 Pressure head.
2 Static-pressure aperture.
3 Twin nosewheel-doors.
4 Nosewheel-leg door.
5 Rudder pedals and toe brakes.
6 Cyclic-pitch control.
7 Collective-pitch control.
8 Centre console (see cockpit diagram, p. 196).
9 Main instrument panel under shroud.
10 Transition panel.
11 Windscreen wipers.
12 Wiper motors.
13 Wiper control panel, and brake pressure.
14 Sliding side-windows.
15 Nosewheel jack.
16 Breaker strut.
17 External supply sockets, 28 v, 112 v.
18 Flight-deck door.
19 Jacking point.
20 Cooling air for radio and electrical racks.
21 Integral-stair balance springs.
22 Upper half-door.
23 Light channel-section frames.
24 Angle-section longerons.
25 Continuous seat-rails.
26 Lightweight laminated floor panels.
27 Compressor control linkage.
28 Rudder cables and linkage.
29 Integrator (rudder, pitch, compressor).
30 Wing/fuselage connections (four).
31 Tubular pylon structure.
32 Fairing, attached only to 31.
33 Pylon/wing connections (four).
34 Fuel collector tank.
35 Fuel pumps.
36 Fuel tank vents.
37 Fuel (gravity) fillers.
38 Pressure refuelling point.
39 Fuel filter.
40 Fuel regulators.
41 Fuel-cooled oil cooler.
42 Central beam for rotor-head controls.
43 Hydraulic header tank, systems 1 and 2.
44 Hydraulic reservoirs.
45 Rotor-head main bearing casing.
46 Head/pylon connections (four).
47 Steel hub centre.
48 Steel stub-arms with flapping hinges.
49 Steel inner spars (see airflow diagram, p. 197).
50 Steel end-fittings.
51 Welded trifurcated duct.
52 Steel channel-section blade-root fittings.
53 Machined from solid.
54 Folded angles.
55 Fuel lines.
56 Ignition lines.
57 One-piece wrap-round skin.
58 Fluon rings.



Dimensions and weights: Fuselage length, 58ft 8in; height overall (to top of rotor head), 22ft 2in; fuselage interior, 46ft long, 8ft wide, 6ft high; floor height above ground, 3ft 5in; wing span, 46ft 6in; wing gross area, 475 sq ft; rotor diameter, 90ft; rotor disc loading, 6.14 lb/sq ft; rotor blade chord, 27in; Rotol propellers, 13ft diameter; tare weight, 24,030 lb [weight breakdown (lb): structure, 7,039; rotor system, 5,312; powerplant, 7,364; fuel and air supply, 881; fixed power services, 1,987; safety measures, 279; equipment, 528; fixed furnishings, 640]; laden weight, 39,000 lb (removable load, 1,797 lb; operating load, 6,273 lb; payload, 7,400 lb). Basic performance data are given on page 196.

59 Pitch-change mechanism, outer casing.
60 Pitch-change linkage.
61 Scissor link.
62 Fuel distributor.
63 Cyclic (lateral) jacks (see p. 197).
64 Cyclic (fore and aft and collective) jacks.
65 Shaft drive to 66.
66 Rotor gearbox (high-pressure fuel pump, hydraulic pump, tachometer, generator).
67 Rotor brake.
68 Oil tank (head lubrication).
69 Steel casting; duct takes control system loads.
70 Lightweight ducting.
71 Bellows walls to allow expansion of duct.
72 Fluid coupling.
73 Plenum chamber.
74 Auxiliary compressor (mass-flow (19.5 lb/sec).
75 *Firewalls.*
76 Tubular engine mounting, four-point attachment.
77 Engine air intake.
78 Engine compressor section.
79 Engine combustion section.
80 Engine turbine section.
81 Bifurcated jet-pipes.
82 Starter motor.
83 Oil cooler and fan unit (low-speed cooling).
84 Oil tank.
85 Oil-cooler airflow.
86 Drive shaft to 87.
87 Auxiliary gearbox (28 v and 112 v generators), hydraulic pump.
88 Generator cooling air.
89 *Napier Spraymat de-icing.*
90 Main undercarriage retraction jack.
91 Drag strut.
92 Sway braces.
93 Leg door linked to leg.
94 Twin wheel-doors, linkage and snubber.
95 Glass-fibre moulding.
96 Hinged leading edge (to engine and propeller controls).
97 Inspection panels.
98 Fuel tank bay inner skin Reduxed to ribs.
99 Retractable landing lamp (each wing).
100 Rubber mouldings.
101 Emergency undercarriage-down valve.
102 Emergency fin-fold valve.
103 Tailplane mounting points.
104 Door-operating jacks.
105 Door-operating buttons on fuselage wall.
106 Door latch.
107 Electric trimming actuator.
108 Rudder power actuator.
109 Fin-folding jack.
110 Tail bumper.

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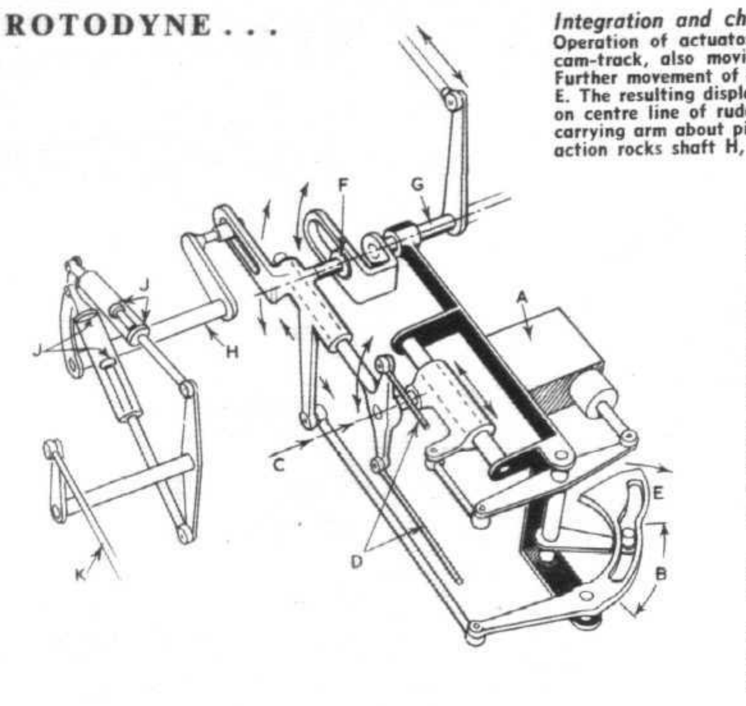


Integration and change-over of rudder and differential pitch shown diagrammatically: Operation of actuator in cruising-pitch conditions moves lever through the ineffective sector of cam-track, also moving slide carrying the pivot operating the pitch-control rods D collectively. Further movement of actuator, out of cruise condition, moves lever to effective sector of cam-track E. The resulting displacement of cam and associated linkage displaces roller F from neutral position on centre line of rudder movement input shaft G. Rudder movement then swings roller F and its carrying arm about pivot C, moving pitch controls D differentially. Movement of roller F by rudder action rocks shaft H, which (via butting stops J) imparts a unidirectional movement to K, limiting the auxiliary compressor output.

completely independent, their relative positions are retained when tilted. Because of the rotor, "weight wires" are not practicable and the model has to be extensively lead-ballasted. The rotor, which has blades with steel leading-edges and Tufnol trailing-edges, is not dynamically similar, its purpose being to produce downwash—the real unknown quantity—and not to determine the characteristics of the full-scale rotor, which was developed on the White Waltham rigs. It was as a result of these tunnel tests that the additional fins were added above the tailplane.

It appears that the Rotodyne will become an "aeroplane" soon after it develops forward speed, for the model characteristics are linear after some 40 ft/sec right up to 400 ft/sec. It should be noted here that there is an essential difference even between the modified Jet Gyrodyne and the Rotodyne, because the stub wing of the former carries no appreciable load and, in fact, the rotor cannot maintain level flight in autorotation. Thus, there are definite limitations to the knowledge to be gained from that research aircraft.

Flight Characteristics and Control. The Rotodyne will, essentially, be controlled as a helicopter; that is, the stick gives cyclic pitch and the throttle is a twist-grip on the collective-pitch lever. The rudder pedals operate the rudders and also superimpose differential pitch-change on the propellers to give yaw control. At present, the elevators are electrically operated (by a button on the stick) for trim only, and there is a large trimming tab on the port wing.

Ignoring mechanical details and gas dynamics for the moment, there are several aspects of the control system, and the handling of it, peculiar to this configuration.

Because the rotor blades are driven from the tips, there is no need for drag hinges; flexure in the tubular steel inner spars (between the rotor head and the aerofoils) is sufficient to meet the uneven loading of the cut-jet case.

The rotor is the sole control in roll and pitch and would continue to be available even in the case of both engines stopping, since it drives its own emergency hydraulic supply. The large "elevators" have balance-tabs to relieve hinge moments and so assist their electric screwjacks, but they are, nevertheless, purely trim surfaces. They have, however, been designed for use as elevators should this prove desirable. Likewise, ailerons can be fitted should these be thought preferable for cruising conditions.

The yaw control is a *mélange* of rotating and fixed-wing practice. Above a forward speed of 80 kt the rudders alone control the aircraft in yaw. They are actuated by Fairey Hydroboosters, not because of large loads but because wind-tunnel results suggested that during hovering in a side-wind there would be feed-back of a beat from the rotor downwash.

Below 80 kt, progressively more differential propeller-pitch control is introduced to replace the rudder moment, which gradually falls off with speed although the rudder surfaces retain full movement all the way. The differential propeller pitch-change is introduced by a mechanical linkage from the auxiliary-compressor clutch control. When these compressors are clutched-in to feed the tip jets, considerable power has to be "reserved" for the yaw control from each engine. Precise adjustment of this extremely tricky feature will obviously be a matter for trial and error. It is, however, of the following order: the differential pitch-change starts to operate when the propeller blade angle is reduced to 40 deg and its range increases to a maximum of about 5 deg positive, 5 deg negative, about the zero-thrust setting.

The dominating factor in the design of this system has been to allow for the one-engine-out case in a practical manner likely to meet with the approval of the airworthiness authorities. It is calculated that the Rotodyne should be able almost to hover on one engine, at say 10 kt forward speed, under full control. In the unlikely event of both engines failing, the aircraft could probably achieve an autorotative descent with a flare-out to a contact that would save passengers, though damaging the aircraft. It has, however, been specifically designed to be flown-on after crossing the hedge at 50 m.p.h., and nosewheel and wheel-brakes have been stressed accordingly.

Evolution of the yaw control has occupied more time than any other detail on the aircraft. The work has been a joint effort by Fairey, Napier and Rotol.

After this, it is pleasing to be able to note that the transition from one form of flight to the other has proved on the Jet Gyrodyne to be simpler than expected. At least five M.o.S. pilots have flown solo after only an hour's instruction and practice.

There is, too, that vexed question of the rotor downwash on the fixed surfaces when hovering. Downwash velocity is graded steeply toward the blade tips, owing to their higher airspeed, and it appears that little of the Rotodyne's horizontal surface area is in the critical zone. Estimates varied between 3 per cent and 6 per cent, so 4.5 per cent was allowed for—and was almost exactly confirmed by the tunnel tests. Conversely, it seems that the downwash creates a positive pressure lift from the wing during hovering in the ground cushion.

Fatigue and De-icing. Following the principle of building a commercial proposition from the start, Fairey tackled the rotor fatigue problem vigorously. Except for the light trailing-edge boxes, high-tensile steel has been used throughout, and the design stress levels are low enough to ensure an infinite life—only 4.5 per cent of the ultimate for pierced parts. These design figures are the subject of very careful checking on the test rigs, while the rotor of the first aircraft is positively packed with built-in internal strain-gauges.

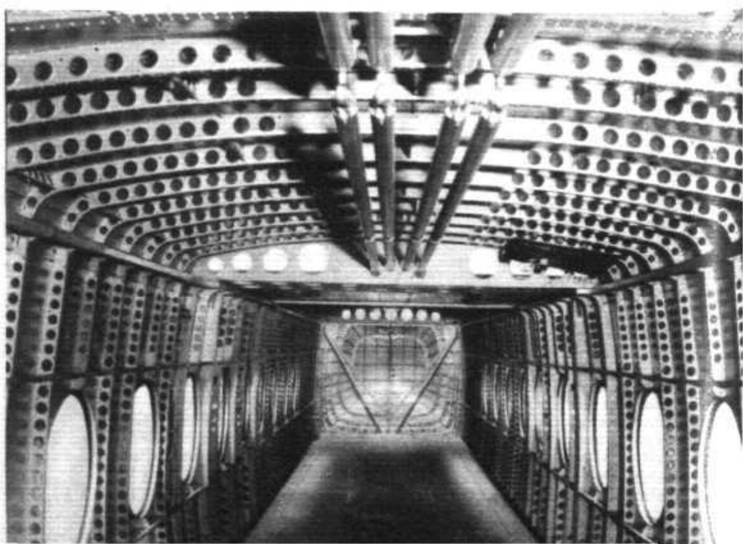
Another realistic approach to commercial operation is full provision for de-icing and cabin heating. Here, Dr. Hislop has concentrated upon an ample electrical supply from a 40 kW alternator on each engine, having discarded the idea of combustion heaters.

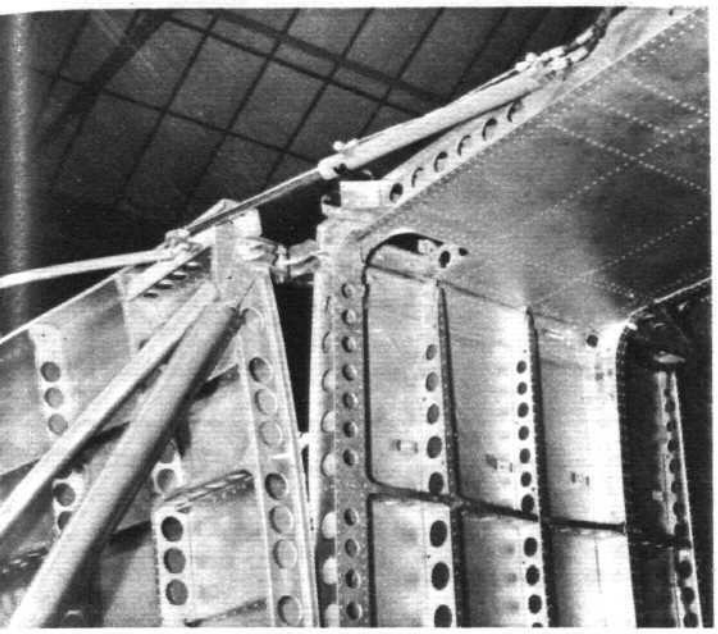
The actual form of blade de-icing remains to be decided, as there are some years of testing ahead before it will actually be necessary, during which time some definitive version may have been developed. In any case, the electrical power is there, ready for anything. Incidentally, it is worth recalling that, as the maximum tip-speed is 720 ft/sec (almost 500 m.p.h.), anything attached to the blade surface would—literally—take a beating.

For the fixed surfaces and the Eland air intakes and spinners Napier Spraymat has already been stipulated, and the Rotol propeller blades likewise have a thermal system. Cockpit and cabin heating will be by a simple system of ducting air over electrical heating coils.

The apparently obvious method of de-icing the rotor blades by compressor air, since it is delivered at over 250 deg C, is in fact a delusion. In the first place the three delivery ducts are not adjacent to the rotor blade skin; in the second, considerable power would have to be provided to drive the auxiliary compressors, so

The cabin, looking aft towards the clam-shell doors.





A hinge of the clam-shell doors, showing the stress-transmitting interlocking jaw fitting and the tubular diagonal brace.

that a prohibitive fuel allowance would have to be made for de-icing.

Fuselage. The many factors peculiar to the Rotodyne have made it necessary for Fairey to do a large amount of basic research to meet the loads and conditions involved. This, of course, refers to the rotor, drive and engine installation; the airframe itself is essentially simple, a fact in line with the principle of making a commercial, saleable product from the start. The "packing-case" fuselage, with clamshell tail doors, is another obvious application of this outlook. It may conveniently be described on a unit-by-unit basis, starting with the simple airframe and ending with the highly ingenious rotor head.

The slab-sided, essentially rectangular box is of conventional construction, with closely-spaced pierced-channel frames, intercostals of similar shape and a skin varying from 15 s.w.g. to 24 s.w.g. Slightly curved and much deeper underfloor built-up cross members, plus four longitudinal beams, are designed to accept concentrated freight and vehicle loads through robust floor panels. The fuselage is assembled from pre-fabricated sides, top and bottom prepared on Fairey envelope jigs.

At the front the stressed-skin box is completed by a bulkhead, with a central doorway, to which the glazed cockpit unit and floor box (which carries the nosewheel loads), are attached as a unit. The forward door is in two parts, with a small lift-up top and integral-stair lower section. The latter is spring-balanced so that it can be manually operated by the handrail on the after side, which is un-clipped and swings inboard as a lever.

The clamshell doors are operated by two Fairey hydraulic jacks acting on their upper coamings. Tubular braces on the doors in the plane of the rear fuselage frame complete this latter structure, when the doors are shut, through self-locking fittings.

Wing. This is a one-piece unit—the span is only 46ft 6in—even though there is a marked difference outboard of the Elands, where the structure is very much lighter. It is essentially a conventional two-spar structure with solid webs, reinforced by shear stiffeners and L-section booms. Running across from one outer-engine rib to the other, the spar booms are machined extrusions, but outboard they are of folded light-alloy sheet.

The two main ribs at each engine bay have solid webs, extruded L-section booms and Z-section shear members, as also have the ribs at the fuselage sides and the inter-spar members in the plane of the rotor pylon "feet." The stress-bearing inter-spar surface is in the form of permanently attached double-skin panels of unusual construction. The fore-and-aft contour members and the two sets of spanwise stiffeners are pierced channel sections which are riveted to the skin in envelope assembly jigs. The light inner tank-skin is Redux-bonded to a rectangular channel-section grid of light alloy which mates with the pattern of the stiffeners and contour members, to which it is blind riveted. The tanks are Marston Excelsior bags, each of which is inserted and serviced through two screw-on panels in the under-surface.

There is a false spar at the leading edge, ahead of which is a lift-up access door to the engine plumbing. The trailing edge and wing tips are simple conventional parts.

Tail Unit. The large, rectangular tail surfaces are quite conventional in construction, with two solid-web spars, pierced-and-flanged ribs and stressed skin. The bottoms of the fins are strut-braced to the fuselage. The hydraulically-operated rudders have inset hinges, but are otherwise unbalanced. A twin-motored electric actuator operates the elevator surfaces and is assisted by geared balance tabs.

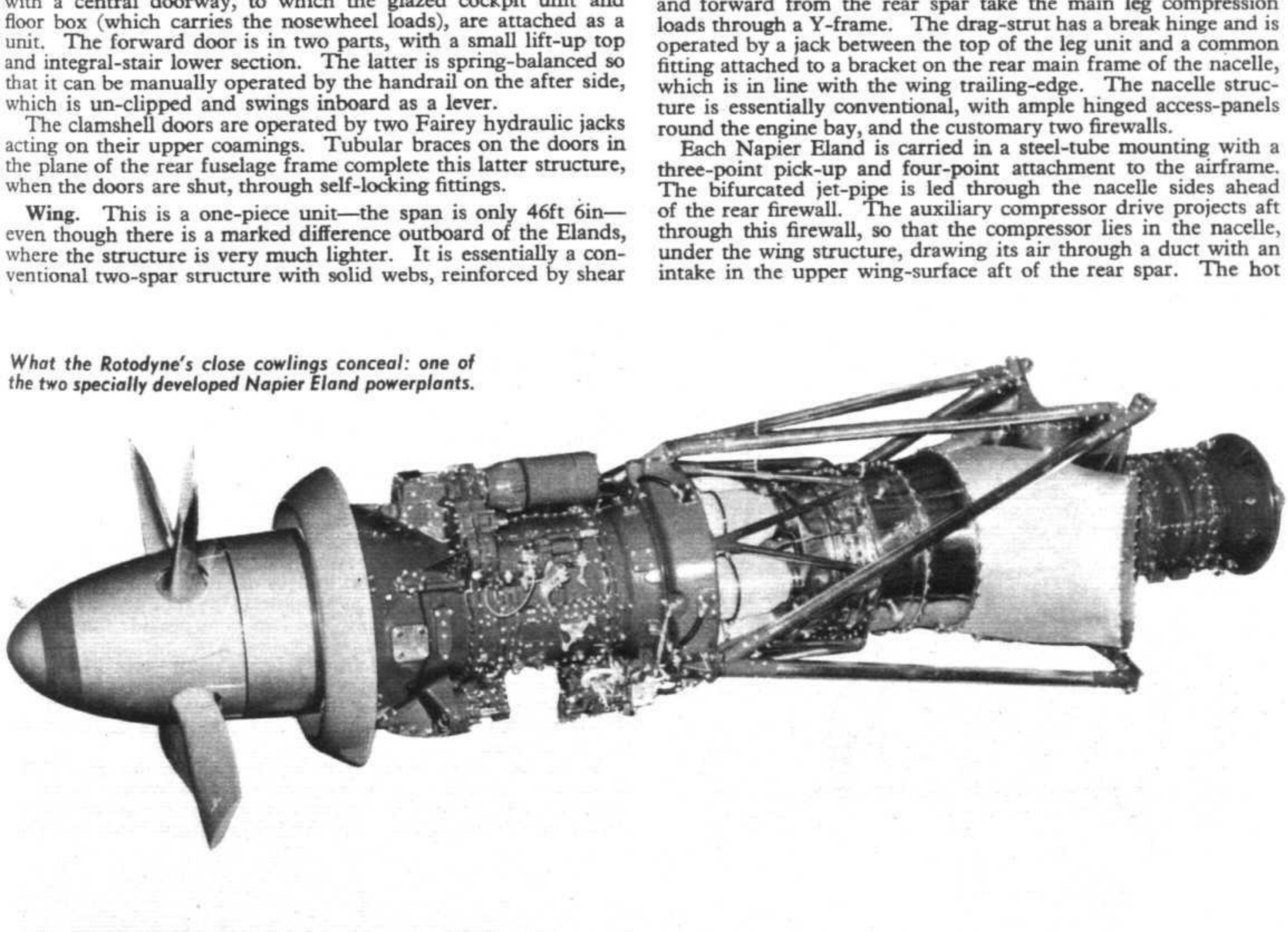
The upper fins, which are required to compensate the loss of side area caused by the blunt "freighter" stern, are folded down hydraulically to give additional rotor clearance during run-down, when there may be a tendency for the blades to flap.

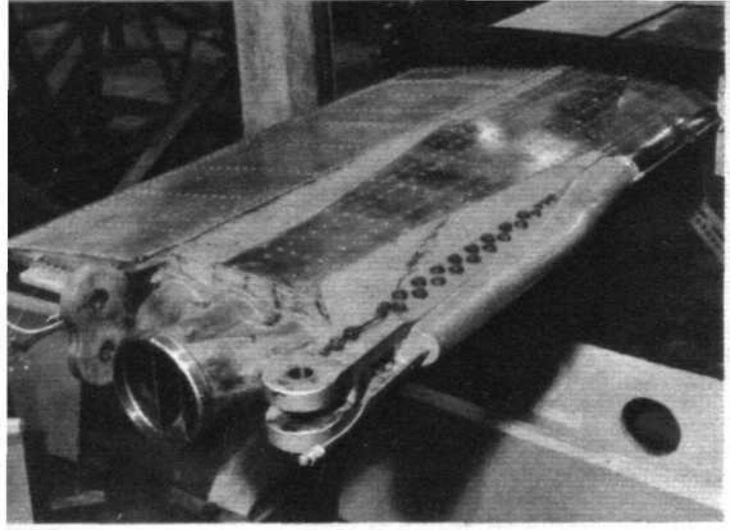
Alighting gear. The main and nosewheel units, together with their actuating jacks and control valves, are of Fairey design. Twin wheels and anti-torque scissor-links are fitted to each unit, brakes to the main wheels. The nosewheel is retracted forward, the mainwheels backward. Emergency operation is by individual Hymatic air bottles, which are discharged into the normal jacks. On the question of "free-fall," Fairey point out that even if the main legs did not lock under gravity the aircraft could be flown backward to put air pressure on the fairing doors.

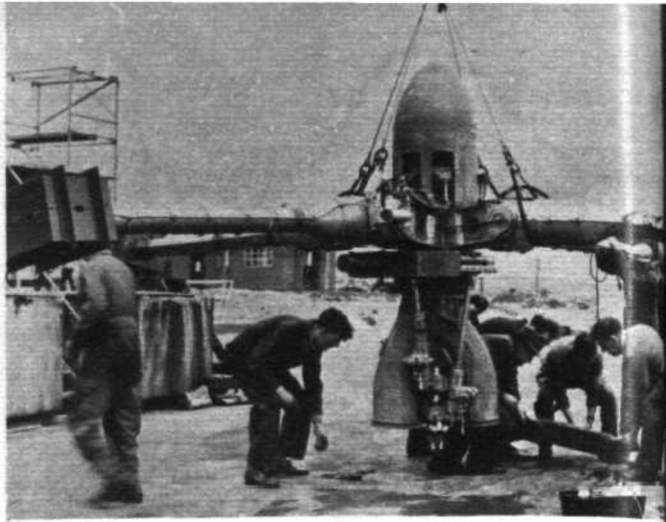
Engine and Nacelles. The nacelles are underslung from fittings on the lower booms of the main spars, the front spar fittings being shared with the upper engine-mounting attachments. A bulkhead in the plane of the front spar carries the lower engine-mounting fittings. Built-up side-members carried down and forward from the rear spar take the main leg compression loads through a Y-frame. The drag-strut has a break hinge and is operated by a jack between the top of the leg unit and a common fitting attached to a bracket on the rear main frame of the nacelle, which is in line with the wing trailing-edge. The nacelle structure is essentially conventional, with ample hinged access-panels round the engine bay, and the customary two firewalls.

Each Napier Eland is carried in a steel-tube mounting with a three-point pick-up and four-point attachment to the airframe. The bifurcated jet-pipe is led through the nacelle sides ahead of the rear firewall. The auxiliary compressor drive projects aft through this firewall, so that the compressor lies in the nacelle, under the wing structure, drawing its air through a duct with an intake in the upper wing-surface aft of the rear spar. The hot

What the Rotodyne's close cowlings conceal: one of the two specially developed Napier Eland powerplants.







(Left) A rotor-blade root, showing re-inforcing skin laminations, attachment fittings, fuel pipe in leading edge, and the trifurcated air-duct union. (Right) Preparing the rotor head for one of the many test programmes; this picture gives a vivid idea of its size.

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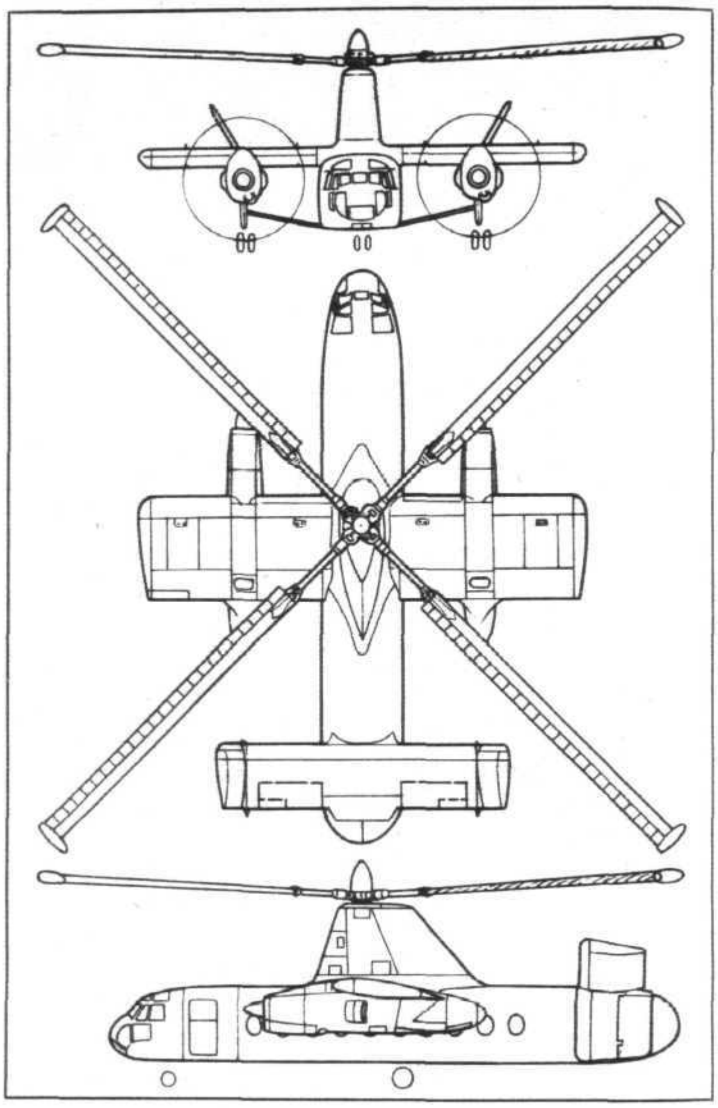
air from the auxiliary compressor is delivered upward, ahead of the firewall, into a Nimonic 75 elbow which connects with the duct in the leading edge. Apart from this and the differential propeller-pitch control, the only major non-standard feature in the Eland installation is the fan-cooled oil cooler, for which Napier supplied a special drive.

Rotor System. This is essentially an all-steel structure (to overcome the fatigue-life problems associated with high-strength light alloys), considerable resort being made to nickel alloys in the combustion- and compressed-air-delivery zones.

Rotor Blades. Each 45-ft rotor blade is a two-piece unit—the aerofoil structure and the inner spar (in this connection one regards the combustion chamber as a separate entity, even though it has a considerable influence upon the blade structure).

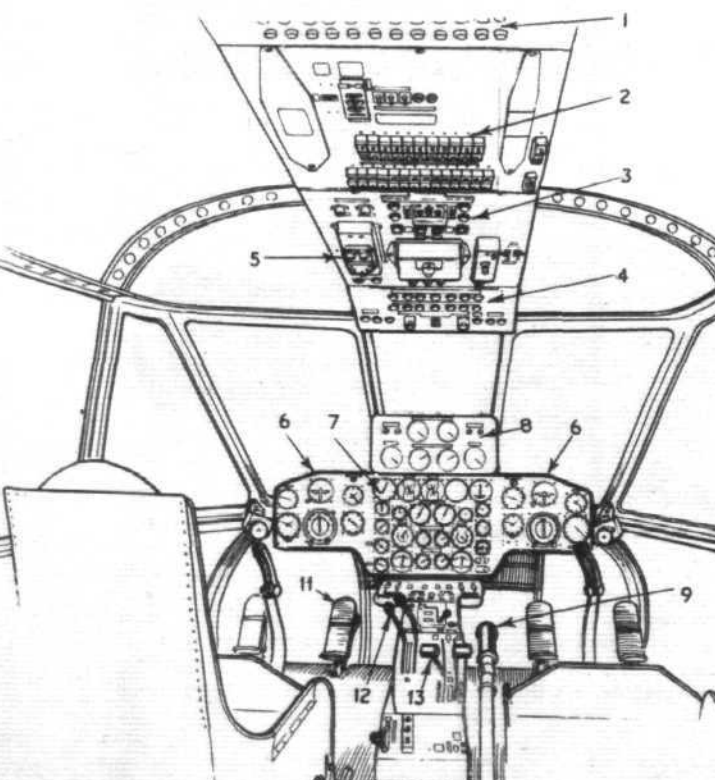
The blade aerofoil is a symmetrical one of low drag, but not laminar flow. Because of the great importance of fore-and-aft c.g. position on flutter, the blade is designed with a solid steel leading-edge and very thin light-alloy trailing-edge. The load-carrying torsion box has a massive machined-steel (D.T.D.730) front spar and a 16 s.w.g. stainless-steel (D.T.D.166) rear spar made from two folded L-plates riveted together to form a channel section. The pierced rib blanks, closely spaced, are made in thin-gauge D.T.D.171 stainless steel. They are attached to the 20 s.w.g. D.T.D.166 skin by countersunk Monel rivets.

Down the interior of the blade run the three Accles and Pollock air-delivery tubes of T.58 steel, each in one piece, with the gauge reduced in steps from 20 s.w.g. at the root to 29 s.w.g. at the tip. These tubes are constrained at the root only and they are passed through clearance holes in the ribs until they are located as a free sliding fit in the intake cuffs on the combustion chamber. Fluon rings are used to position the tubes at alternate ribs and prevent rattling. Fluon is a plastic which retains self-lubricating properties up to 250 deg C, so there is no restriction on the sliding of the tubes.



Basic performance (estimated): cruising speed, 170 m.p.h.; payload, 40 to 48 passengers for ranges up to 430 miles; vertical rate of climb at sea level at maximum power, 1,670 ft/min; direct operating cost per passenger mile, about 3 pence at 100 miles range, falling to 2½ pence at 250 miles and 2.3 pence at 450 miles.

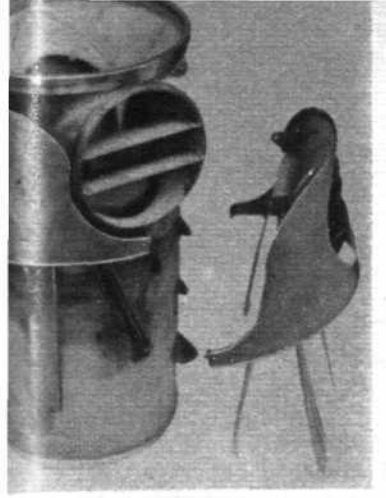
Cockpit layout: 1, fuse panel; 2, circuit breaker; 3, fuel system; 4, warning lights; 5, G.M. Mk 48 compass control panel; 6, flight instruments; 7, engine and auxiliary instruments; 8, engine transition panel; 9, collective pitch control (dual on port side); 10, screen-wiper control; 11, toe brakes; 12, propeller pitch control levers; 13, power levers.



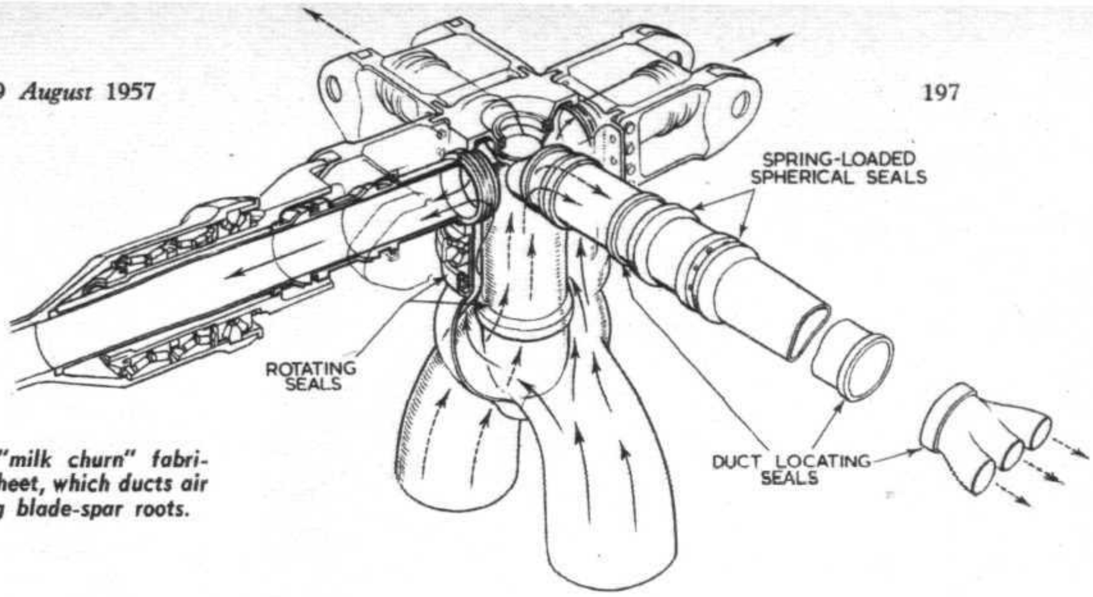
The leading-edge spars are worthy of note, for they are machined in pairs from a 35-ft rolled billet supplied by the English Steel Corporation—believed to be the longest high-tensile-steel billet made in this country. After parting and rough machining they are returned to Sheffield for heat treatment. Final machining introduces two spanwise grooves in the leading edge which form recesses for the fuel pipe and the ⅜in diameter steel c.g. balance rod—lateral c.g. is adjusted by weights at the root end and shims on the blade skin at the tip. The aim is to provide fully interchangeable balanced blades.

The steel skin is formed from a single piece—root to tip and top to bottom flange of the rear spar. The leading-edge radius is cold-drawn by Fairey on a special apparatus. Assembly of the skin to the ribs is done in a type of double envelope jig developed for the purpose.

At the tip of the blade spars are the simple fittings for the combustion chambers. At the root the aerodynamic torsional loads are diffused by skin laminations into the flanges of fittings bolted to the two spars. The high centrifugal loads (a blade



(Left) The "milk churn" fabricated from sheet, which ducts air to opposing blade-spar roots.



Air from the port auxiliary compressor enters the inner duct of the light-alloy "trouser" casting and the starboard compressor supplies the annular duct around it. The sketch also indicates some of the sealing problems involved in leading pressurized air at 250 deg C through flexing ducts. Note also the spar-root taper roller bearings.

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weighs 622 lb, plus the tip jet at 45 lb) are taken through the rear spar fitting. A cuplike machined forging "gathers" the separate spar fitting loads and transfers them to the inner spar, to which it is attached by an internal ring nut.

This inner spar is a thick-walled mace-shaped tube machined from a solid S.99 forging. Its bore connects the rotor head air-delivery to the three blade ducts by way of a neat little welded stainless steel "trifurcated" duct. The root cup of the inner spar fits over the bearings of the flapping-hinge fork and pitch-change axle assembly. On the outside of the inner spar are clipped the fuel supply line and the ignition loom.

The rotor blade is completed by 24 light-alloy trailing-edge boxes with 30 s.w.g. skin. To allow for differential expansion and blade flexing, each box is fastened to the spar at its inner end only, the outer end being free to float on a pin and slot. The electrical loom is threaded through plastic tubes let into the ribs of the trailing-edge boxes.

Rotor Mountings. The rotor is carried on a bolted H.T. steel-tube (T.60) four-legged "tower." The streamlined fairing round this structure is anchored only to the four fuselage fittings for the "tower," otherwise it is fully floating so as to allow for strain in the tubular structure. On the top of the tower are four pairs of triangulated tubes, the four apices of which carry the main bearing housing. This last is a 30-in diameter circular channel boxed on its underside by a bolted steel plate.

Air Delivery. The air from each Eland feeds only one pair of (opposing) rotor blades, so that in the event of engine failure the efficiency of the system is not impaired. The leading-edge air ducts are fabricated by spot welding from Nimonic 75 sheet, using a crimped, or bellows, form to allow for thermal expansion. When the ducts reach the rotor pylon there is the problem of maintaining separate delivery into the rotating head. To achieve this a light alloy casting, known not unnaturally as the "breeches pipe," accepts the two air flows in its "legs" and delivers them through concentric annuli which feed into the "milk churn." This is a fabricated Nimonic sheet assembly reminiscent of a Coles chimney cowl.

The "churn" is a concentric annular duct mounted in the rotating rotor-hub which ingeniously delivers the air from each duct to opposing pairs of blades. With the help of cascades to turn the flows and careful matching of cross-sectional areas the duct losses have been kept low. The rotating joint between the "breeches pipe" and the "churn" is sealed by a graphite-impregnated sintered bronze ring. Dividing the two flows—normally without a pressure drop, but vital after engine failure—is a labyrinth seal. Up the centre of the assembly is the airtight tube within which the concentric control tubes operate; and at the centre of everything is the conduit for fuel pipes and ignition leads.

The combustion system cannot be described in detail here, but the principles, and the development history, were fully dealt with in *Flight* for May 3 (page 575).

Rotor Head. The basic problem in the rotor head was how to get the pitch-change controls round the obstruction offered by the air ducting. It was solved by mounting the actuating linkages and swashplate on top of the rotating head, with the operating jacks anchored below the main bearing housing, the action being transmitted by concentric slide/torque tubes.

The high-tensile-steel central rotor forging rests in the double taper-roller main bearing, in which it is locked by a large ring nut. On the bottom of the forging is mounted a toothed ring which drives the pinion and shaft to the auxiliary gearbox and rotor brake. Bolted to the upper part of the central forging are the stub arms which hold the flapping hinges.

These are large journal bearings that mate with the flapping-hinge fork and pitch-change axle assembly inside the cup-shaped root of the inner spar. The axle assembly is composed, in effect, of concentric sleeves with a double taper-roller thrust bearing for the c.f. loads and two double/taper-roller feathering bearings. Inside the flapping-hinge fork there is a hemispherical self-centring joint for the air duct.

The two pairs of control jacks—with tandem pressure chambers fed continuously by main (duplicated) and emergency hydraulic supplies—act on sliding collars mounted on hemispherical bosses on the actuating tubes. The upper collar rotates the outer of the two control tubes to displace, through its canted head, the fore-and-aft cyclic-pitch linkage, while the lower one similarly operates the lateral cyclic-pitch linkage through the inner tube. The two "fore-and-aft" jacks operate together to raise and lower the swashplate (which has a driving link to one rotor-blade stub arm only) to give collective pitch change. A splined extension at the foot of the operating tube allows vertical displacement for collective-pitch control without affecting the lateral cyclic-pitch jacks.

The various bearings in the control head are supplied with oil, the unit being sealed by two bellows. The oil drains back to a sump, from which it is pumped by the rotor-gearbox pump. The main bearing is likewise supplied by oil from this gearbox.

The central tube to the top of the rotor head carries a conduit containing the fuel lines, ignition leads and light-up telltale leads to the fuel distributor manifold and respective sliprings. On the prototype there are many additional wires for the strain-gauges, which, of course, are picked up selectively as the test programme is followed.

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Rotor pitch control (airflow omitted for clarity—see sketch above): **Rocking movement applied by paired jacks to the lower set of inclined bearings on the concentric control tubes imparts a rotary motion to the vertical tubes and a corresponding rocking of the upper set of inclined bearings, thus tilting the spider. Collective pitch is obtained by both upper jacks moving in the same sense. The inner tube is splined to allow this vertical movement of outer tube and spider. Small diagram shows principle of inclined bearings.**