HUNTING PERCIVAL P.74

Research Test Vehicle Approaches the Flight Stage: a New Helicopter Philosophy

THERE are three ways of using a gas turbine to provide power for a helicopter. One is to couple it by shaft drive to the rotor in accepted piston-engine style; another is to draw off compressed air from the engine to supply rotor jets—with or without tip burning; and another is to extend, in effect, the jet pipe to the extremities of the rotors, using the whole through-put of the engine to drive the rotor. Examples of the shaft-drive techniques include the Piasecki Transporter (two Allison T38-A-6), and the Sud-Est 3130 Alouette 2 (one Turboméca Artouste 2); the Westland Whirlwind is also being developed with turbines (one Blackburn Turboméca Twin Turmo), and will be shaft driven, as also will be certain Bristol twin-rotor helicopters (two Napier Gazelles). Compressed-air devotees include the Fairey Rotodyne, the Fairey Ultra-light, and the Sud-Ouest 1120 Ariel, 1220 Djinn, and 1310 Farfadet family.

Last week there emerged from the experimental department of Hunting Percival at Luton the world's first exponent of the third technique—the P.74.

Although each gas-turbine system displays advantages of one kind or another over conventional piston-engine designs, use of rotor jets is undoubtedly the most natural way of exploiting the gas-producing potentialities of a turbine engine. Let gas-pressure energy do the work of a mechanical transmission and immediately the helicopter designer is rid of the mechanical couplings which constitute his major development worry and which, because of the fixed relationship of rotor speed to engine speed, limit the operating efficiency of the helicopter.

The jet helicopter is by no means new—its advantages were foreseen the day the jet was born—and today we see flying, with conspicuous success, such machines as the Fairey Jet Gyrodyne and the French Sud-Ouest company's family of helicopters. It is the Hunting Percival/Napier approach to the jet helicopter which is altogether new. Hunting Percival foresaw in 1950 the aerodynamic advantages of a jet helicopter, and that the best efficiency—weight lifted per amount of fuel burnt—could be achieved by a gas turbine whose sole job in life was to deliver gas horse-power rather than thrust or shaft horse-power. The result is the P.74, and so close has been the partnership between engine and airframe/rotor designers that it is in fact difficult to tell where the Napier Oryx ends and the P.74 begins.

The Oryx has been previously described in detail (*Flight* for August 5th, 1955) and it is necessary only briefly to recapitulate the principle of this fine engine. It is a true gas-producer, in which the power left over from the turbine after it has compressed its own air is used to compress further air. This by-pass air mixes with the turbine exhaust, increasing and cooling the flow for ducting to the helicopter rotor. The engine thus consists of two compressors, each with its own air intake and driven by a common turbine. No further combustion is necessary (although reheat at the nozzles is, of course, practicable) and it is interesting—in view of the criticisms levelled at jet helicopters on the score of noise—that the relatively low-pressure flow is not likely to be too disturbing to the ears. (Experience with the P.74 test rotor, although not truly representative with its Derwent powerplant, has tended to show that nozzle noise is in fact barely distinguishable from the aerodynamic swish of the rotors.) Ground runs of the P.74 complete with rotor are due to begin very soon—rotor-less engine runs were first made on December 2nd—and it will be possible then to verify the belief that the P.74 and its commercial derivative the P.105 will be among the quietest helicopters yet flown.

Before we recount the problems that confronted the Hunting Percival and Napier teams, and describe the way in which they were mastered, it is worth setting out the advantages offered by this new conception of the jet helicopter. Foremost, as already mentioned, clutches, couplings, gearboxes and other mechanisms are eliminated from the scene, together with their associated maintenance, vibration and cooling problems. Secondly, since the rotor is gas-coupled to the engine, its speed is not fixed in relation to it and the optimum rotor speed can be chosen for any condition of flight; hence it is possible to achieve lower rotor r.p.m., and therefore greater aerodynamic efficiency and lift, for the same engine power in hovering flight. Comparative curves of power required against forward speed show that theoretically about 10 per cent less power is required to lift the same weight in the hovering regime (as forward speed increases the two curves tend to converge). The potential superiority in economy is clearly evident.

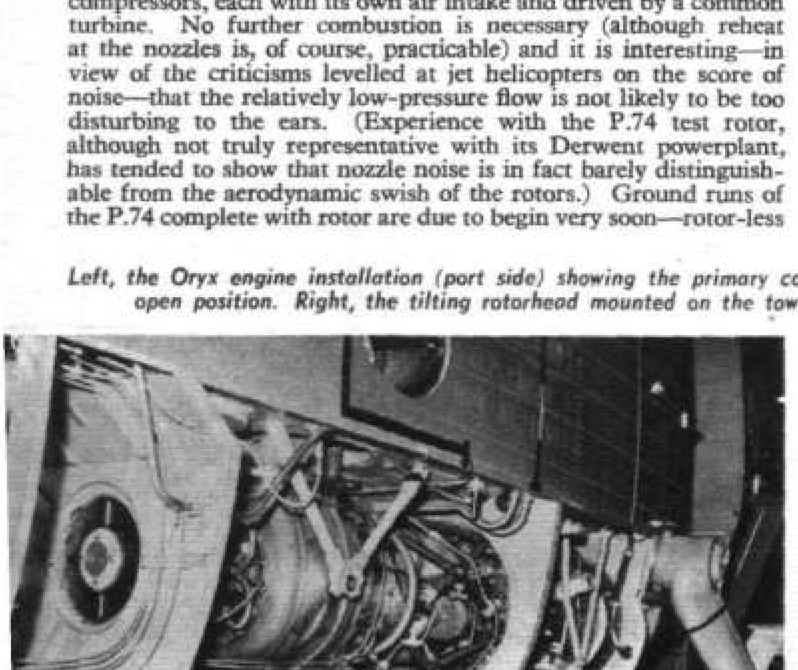
No less advantageous is the fact that the torque between airframe and rotor is of a very low order, consisting only of rotor-bearing and gas-duct friction. Only a small rudder-rotor is necessary for lateral control, and a negligible amount of power is robbed from the main lifting rotor. It is possible that, as a result of P.74 flight trials, a simple fin may be substituted for the rudder-rotor, and the rear fuselage has been made detachable with this possibility in view.

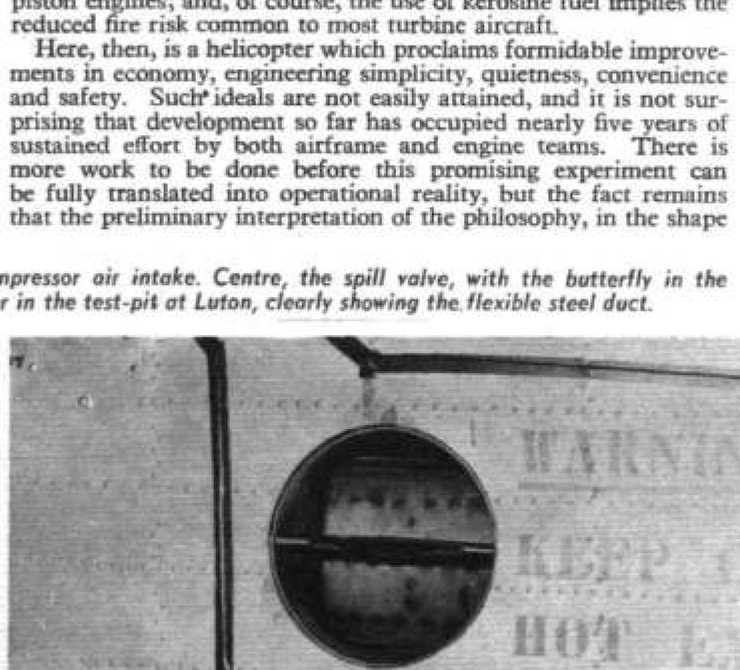
A further virtue of the system is that it makes possible, without recourse to intricate mechanical geometry, the use of a tilting rotor hub. (One tilting-rotor helicopter with shaft drive is successfully operating in the U.S. This is the Doman YH-31 of the U.S.A.F.) As is well known, any inclination of the tip-path plane to the plane of the rotor hub in the classical rotor results in the production of in-plane forces which in turn necessitate the introduction of drag hinges. Being free to tilt, the hub takes up its own position normal to the tip path plane, drag hinges go, the degree of flapping is much reduced, and blade "tracking" tends to be less critical.

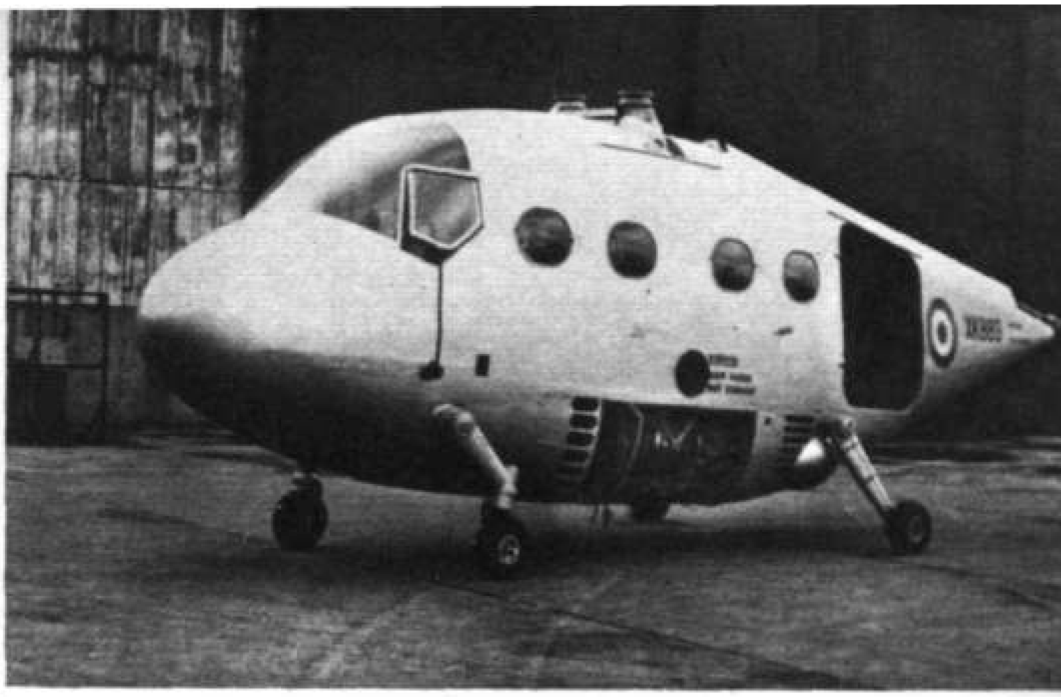
There are yet other attractions; the entire gas output of the engines can be spilt overboard before transfer to the rotor, enabling a full-power check to be carried out by the ground crew without the aircraft becoming airborne; engine and reduction-gear cooling—of special concern to a fully laden hovering helicopter—is no problem; the turbines, being outside the cabin as they are to be on the P.105, will be a welcome aural relief from internally installed piston engines; and, of course, the use of kerosine fuel implies the reduced fire risk common to most turbine aircraft.

Here, then, is a helicopter which proclaims formidable improvements in economy, engineering simplicity, quietness, convenience and safety. Such ideals are not easily attained, and it is not surprising that development so far has occupied nearly five years of sustained effort by both airframe and engine teams. There is more work to be done before this promising experiment can be fully translated into operational reality, but the fact remains that the preliminary interpretation of the philosophy, in the shape

Left, the Oryx engine installation (port side) showing the primary compressor air intake. Centre, the spill valve, with the butterfly in the open position. Right, the tilting rotorhead mounted on the tower in the test-pit at Luton, clearly showing the flexible steel duct.





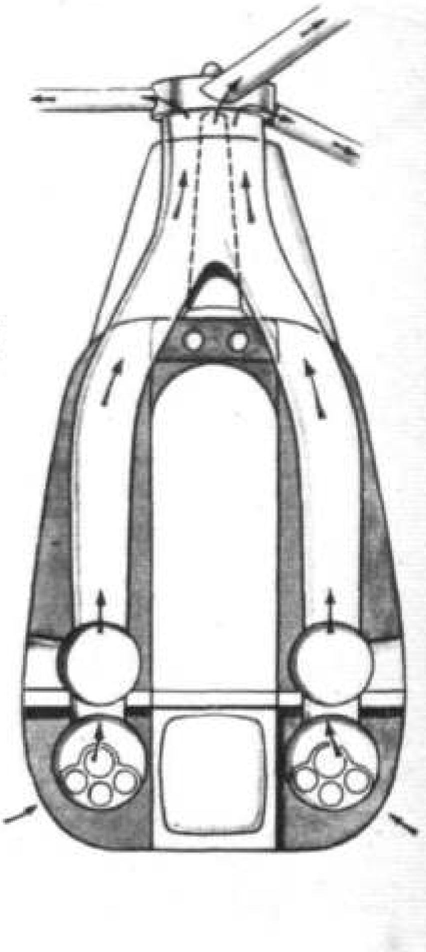


(Above) The Hunting Percival P.74, minus its rotor, had its first outing for engine runs on December 2nd.

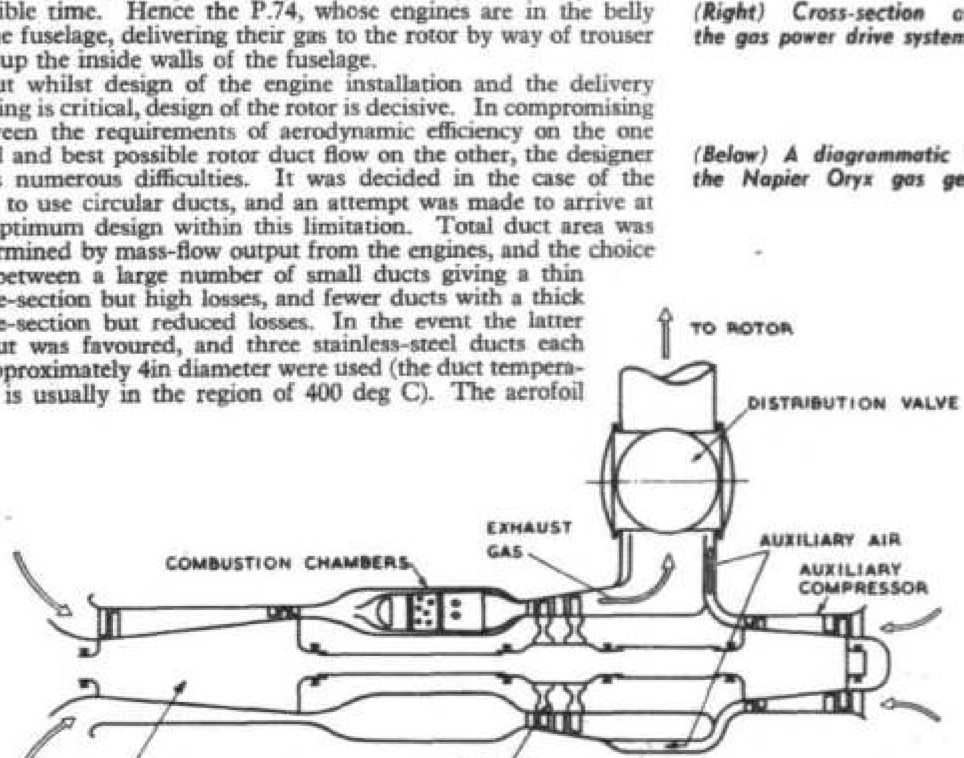
of the P.74, has reached the threshold of its flying trials. The basic problems have been mastered, many of them of an entirely unfamiliar nature.

First, the engine installation. Two engines were deemed desirable, each on one side of the aircraft, feeding, *via* its own "trouser-leg," a common duct to the rotor. When the engines are running steadily, on their "operating line," turbine power matches the sum of primary and auxiliary compressor power; r.p.m. of the turbine and of both compressors are matched; and the auxiliary compressor delivers air at the same pressure as the turbine exhaust which it joins. The delivery flow itself has to satisfy the requirements of the rotor system, performance of which is sensitive to mass flow, tip nozzle area, pressure, and temperature—the upper limit of which is fixed by the mechanical properties of the rotor. Likewise, the ducting from each engine to the rotor head is a most critical part of the system, requiring careful reconciliation between the opposing interests of thermodynamics and engine installation design. Ideally, ducting should be as direct as possible; but the Hunting Percival design aim is to make engines and rotor a compact, individual entity, independent of airframe. We see the expression of this in the P.105, whose rotor/engine group, consisting of an Oryx at each end of a short stub wing just beneath the rotor, can be used in a variety of ways—as an aerial crane, for example. But the development of the ideal engine-to-rotor ducting system, involving lengthy experiment with suitable duct shapes and cascading, is still in progress, and it was clearly desirable to test the principle of the system, using relatively direct ducting, in the quickest possible time. Hence the P.74, whose engines are in the belly of the fuselage, delivering their gas to the rotor by way of trouser legs up the inside walls of the fuselage.

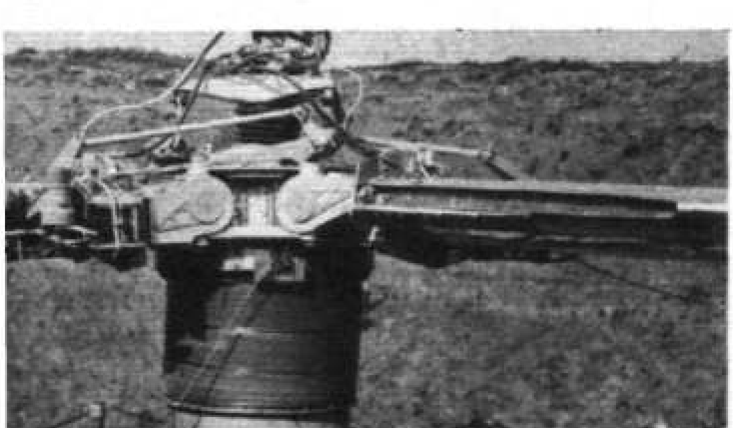
But whilst design of the engine installation and the delivery ducting is critical, design of the rotor is decisive. In compromising between the requirements of aerodynamic efficiency on the one hand and best possible rotor duct flow on the other, the designer faces numerous difficulties. It was decided in the case of the P.74 to use circular ducts, and an attempt was made to arrive at an optimum design within this limitation. Total duct area was determined by mass-flow output from the engines, and the choice lay between a large number of small ducts giving a thin blade-section but high losses, and fewer ducts with a thick blade-section but reduced losses. In the event the latter layout was favoured, and three stainless-steel ducts each of approximately 4in diameter were used (the duct temperature is usually in the region of 400 deg C). The aerofoil



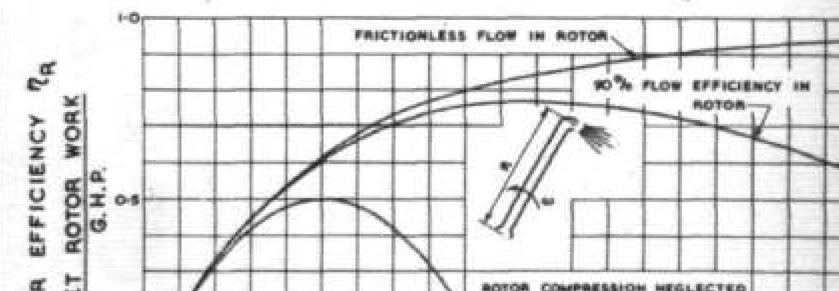
(Right) Cross-section of the gas power drive system.



(Below) A diagrammatic view of the Napier Oryx gas generator.

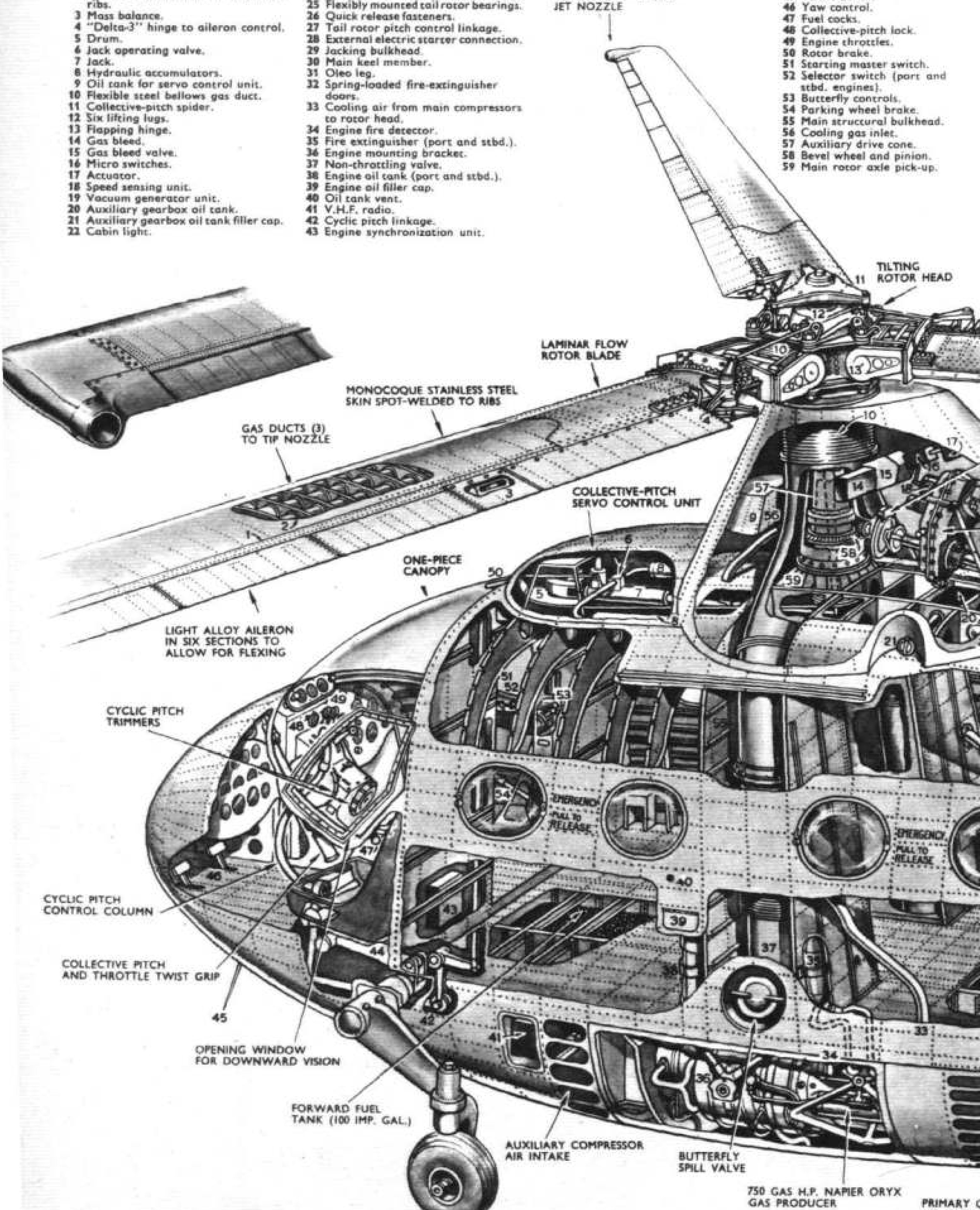


(Below) Variation of rotor efficiency with rotor tip-speed.



HUNTING PERCIVAL P.74 HELICOPTER . . .

1 Rear spar.
2 Asbestos insulation on alternate ribs.
3 Mass balance.
4 "Delta-3" hinge to aileron control.
5 Drum.
6 Jack operating valve.
7 Jack.
8 Hydraulic accumulators.
9 Oil tank for servo control unit.
10 Flexible steel bellows gas duct.
11 Collective-pitch spider.
12 Six lifting lugs.
13 Flapping hinge.
14 Gas bleed.
15 Gas bleed valve.
16 Micro switches.
17 Actuator.
18 Speed sensing unit.
19 Vacuum generator unit.
20 Auxiliary gearbox oil tank.
21 Auxiliary gearbox oil tank filler cap.
22 Cabin light.
23 Rear fuel tank vent pipe.
24 Fuel filler cap near tank (stbd. side).
25 Flexibly mounted tail rotor bearings.
26 Quick release fasteners.
27 Tail rotor pitch control linkage.
28 External electric starter connection.
29 Jacking bulkhead.
30 Main keel member.
31 Oleo leg.
32 Spring-loaded fire-extinguisher doors.
33 Cooling air from main compressors to rotor head.
34 Engine fire detector.
35 Fire extinguisher (port and stbd.).
36 Engine mounting bracket.
37 Non-throttling valve.
38 Engine oil tank (port and stbd.).
39 Engine oil filler cap.
40 Oil tank vent.
41 V.H.F. radio.
42 Cyclic pitch linkage.
43 Engine synchronization unit.
44 Oleo leg.
45 V.H.F. aerial.
46 Yaw control.
47 Fuel cocks.
48 Collective-pitch lock.
49 Engine throttles.
50 Rotor brake.
51 Starting master switch.
52 Selector switch (port and stbd. engines).
53 Butterfly controls.
54 Parking wheel brake.
55 Main structural bulkhead.
56 Cooling gas inlet.
57 Auxiliary drive cone.
58 Bevel wheel and pinion.
59 Main rotor axle pick-up.



enclosing them, although necessarily of thick section—22.5 per cent—was designed to have zero-incidence laminar-flow characteristics up to about mid-chord. The blades are non-feathering, and variation of incidence is taken care of by ailerons, which are in six 3ft sections to compensate for blade-flexing, each attached by three hinges of Ferobestos plastic (no lubrication is necessary) to a C-section "tape"; centrifugal force on the blade tends to keep the aileron in the up position, and downward movement is accomplished by a cable attached *via* a linkage to a classical type of rotor head pitch-control. (Collective pitch is achieved in the usual way by means of a vertical screwjack.) The arrangement is not as complicated as it sounds, and has worked well on the test-rig. When the thermodynamic and manufacturing problems of flattened ducts have been solved a better aerofoil section will result, eliminating the need for ailerons. This is one respect in which the P.105, with its feathering blades, will be an improvement on the P.74.

The blade itself is a pure monocoque of stainless steel, with 22-gauge skin averaging 130 deg C at the root. (Blade de-icing will obviously not be a problem.) Flow at the end of each duct is carefully cascaded through 90 deg into a single discharge nozzle which, as will be explained, has a two-position "eyelid" to vary nozzle area.

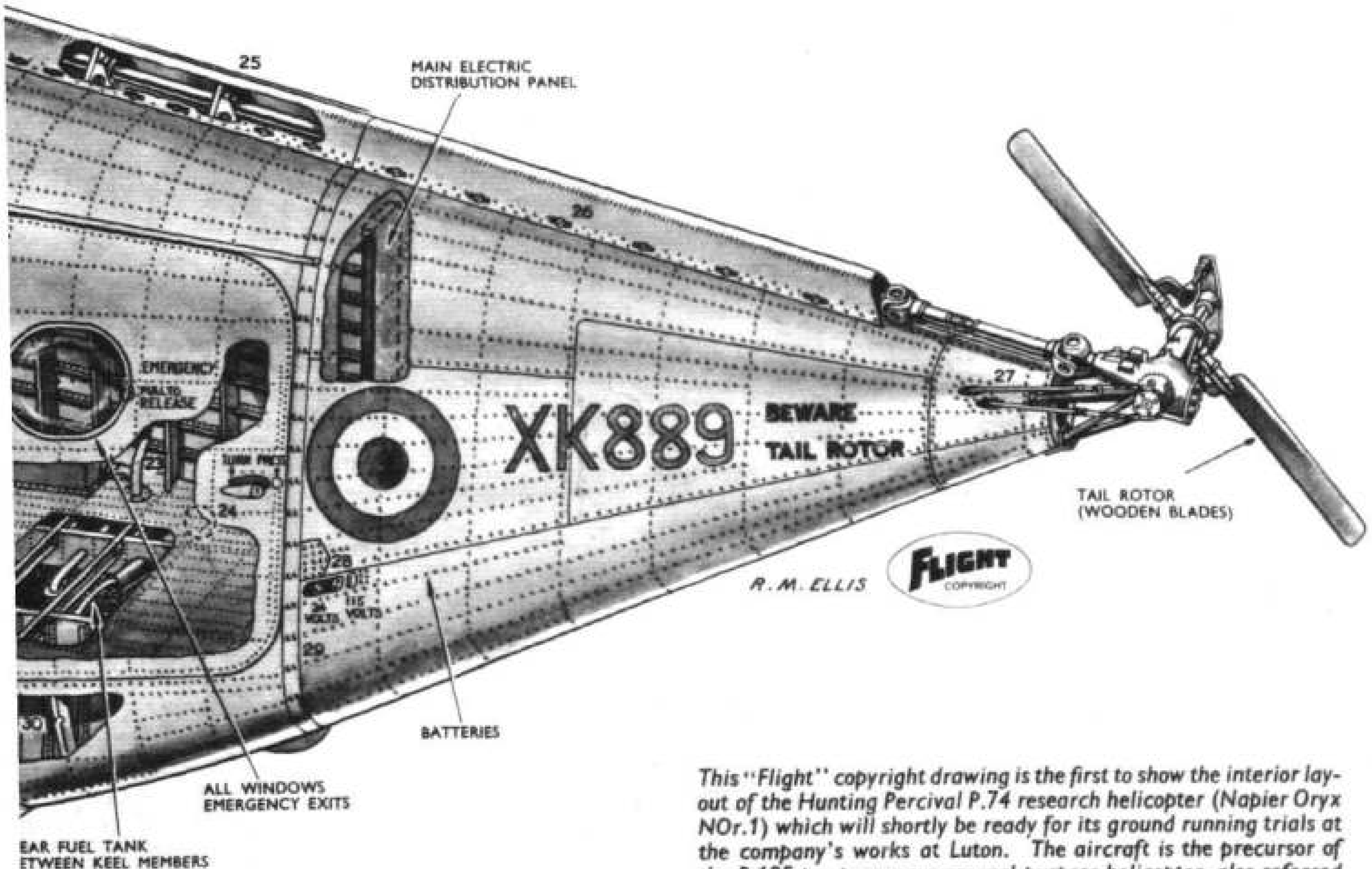
The tilting rotor hub is a fabricated steel structure mounted on Timken taper-roller bearings to permit hub-tilt, this unit in turn being mounted on a spherical bearing. Below this is a flexible gas-tight bellows duct of stainless steel, designed to withstand the complex motion of bending and shearing. A small accessory gearbox is driven off the rotor, from which the rudder rotor takes its drive, and the whole is neatly encased in the rotor hub fairing. A conventional type of friction rotor brake is fitted. Similar flexible ducts, passing between the blade flapping hinges, convey the gas flow into the rotor ducts. The flapping hinges have plastic bearings requiring no lubrication.

It is evident that the centrifugal action of the rotor further compresses the flow, increasing the velocity of the jet, which would theoretically go on increasing until the limiting speed of the rotor was reached. Duct losses obviously preclude this, but it is academically interesting to note that (since rotor horse-power increases with rotor speed) at infinite rotor speed gas horse-power delivered by the engines would be converted entirely into lifting horse-power. This of course is an ideal that is far from attained in practice, where for best aerodynamic efficiency rotor speed should be kept low (P.74 maximum tip Mach number is 0.55). In reality the ratio of rotor horse-power to gas horse-power is of the order of 0.5. The set of curves on page 939 shows the variation of this ratio with velocity for three conditions: frictionless flow; 90 per cent flow efficiency; and without centrifugal compression.

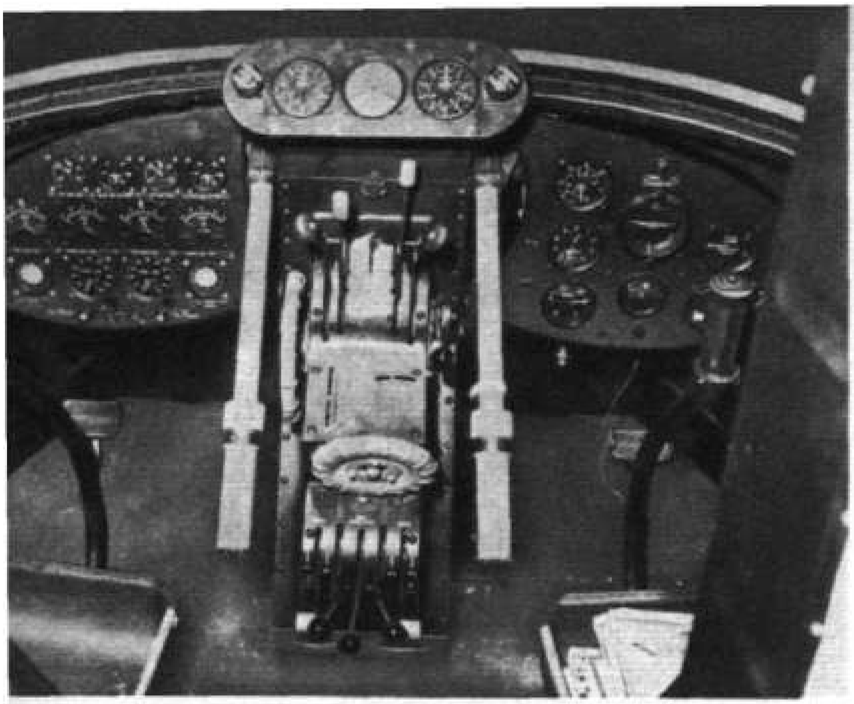
The optimum conditions for best rotor performance have been the subject of prolonged investigation on the Hunting Percival test tower at Luton. As can be seen in the photograph, this was sunk below ground level, for reasons of silence and safety. In general layout the pit is reminiscent of a Roman arena, with its stepped sides and underground entrance passage. A Derwent is used to provide power, its exhaust being cooled to the requisite temperature by water. The installation first ran last March, and the programme of testing the P.74 system has now accounted for some 40 hours of running. This may not seem a great deal on first consideration, yet the amount of data it has yielded is apparent from a typical recent programme in which 40 sets of aerodynamic measurements were taken in a test which, although occupying five days (including a week-end), yielded only 4½ hours of rotor running.

The fact that the two engines of the P.74 deliver gas into a common duct and nozzle means that special care has to be taken to ensure that each engine is running on its "operating line." It was assumed in the early stages of design that the engines would be particularly sensitive to back-pressure, and a comprehensive automatic control system has been developed by Napiers to guard against the likelihood—for example—of the following sequence of events taking place: one engine, its output momentarily falling behind that of its partner, is caused to surge and stall by back-pressure; its partner, working against suddenly reduced back-pressure, simultaneously overspeeds. Napier test work has shown that in actual practice a pair of Oryxes delivering into a common duct and nozzle are not so sensitive to one another as had been at first supposed; but only running tests with the complete P.74 will show how compatible they are. All this, incidentally, will be no problem with the P.105, in which each engine feeds its own duct and nozzle.

The P.74 engine control system is a most interesting piece of engineering, and is the subject of a diagram included in our summary (pages 933-934) of a paper read before the Helicopter Association by Mr. A. W. Morley of Napiers. The two-position nozzle takes care of the engine-out case, when mass flow is of course halved—although, because of lower duct losses, power is

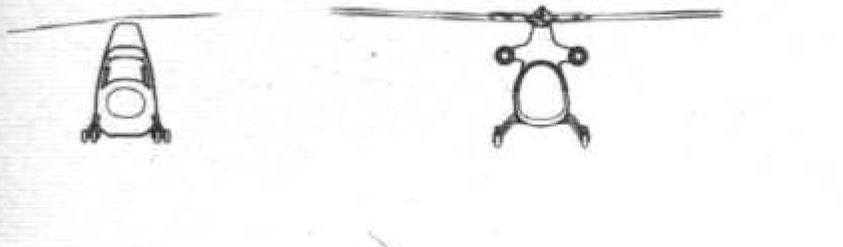


This "Flight" copyright drawing is the first to show the interior layout of the Hunting Percival P.74 research helicopter (Napier Oryx NOr.1) which will shortly be ready for its ground running trials at the company's works at Luton. The aircraft is the precursor of the P.105 ten-passenger general purpose helicopter, also referred to in the accompanying article. The small inset drawing on the opposite page shows one of the blade-tip jet nozzles.



The P.74's cockpit closely follows classical helicopter practice. Of special interest are the engine-synchronizer indicator at the top, and the levers at the foot of the pedestal which select transfer of engine gas output either to the rotor or to spill overboard.

(Right) The neat undercarriage, which consists of a single light-alloy leg with the shock-absorber inside the fuselage.



General arrangements, approximately to scale, of the P.74 research helicopter, and (right) the P.105 ten-passenger commercial vehicle.

HUNTING PERCIVAL P.74 . . .

less than halved. If an engine fails in flight it is automatically isolated from the common duct to prevent flow from the good engine passing into it. This is accomplished by the hydraulically operated "non-throttling" valve at the start of the duct. At the same time the rotor nozzle is moved into its part-closed position by means of a mechanical linkage from this valve, this mechanism being designed to "fail open." Theoretically, to keep the engine on its operating line the area of the rotor tip nozzle should be varied with rotor r.p.m. To avoid this a blow-off valve is fitted in the common duct; this valve is sensitive to rotor speed, and is operated by a governor driven by the accessory gearbox. A similar blow-off system will be included in the P.105.

To start the P.74, each engine "non-throttling" valve is closed, to spill the whole gas output overboard *via* a duct in the fuselage side. A butterfly valve, flush with the skin, allows for varied loading of the engine. Each engine may then be brought up to its correct speed and delivery pressure, at which point the non-

it embodies a number of new ideas. The sturdy four-wheel unde
carriage, for example, is the neatest helicopter chassis we ha
seen. The usual angular struttery carrying each wheel is replac
by a single swinging link, a substantial magnesium alloy castir
the shock-absorber of which is mounted within the fuselag
Wheels are fully castering, and the rear pair are fitted with Palm
pneumatic brakes. Tyre pressures are 80 lb/sq in. All the cab
windows, four on each side, are escape hatches, alternately ope
able from inside and outside.

Construction of the fuselage conforms with accepted helicop
practice in that it may be likened structurally, and without d
respect, to the shopping basket: lifting loads are carried into t
fuselage container by sturdy bulkheads ("handles") and are tak
out by the skin and into the keel by shear members. Unde
carriage landing loads are taken by stiff frames reacted down in
the keel web structure. The door is of a useful size (4½ft by 5
and here it is appropriate to mention that, although the P.
is purely a test vehicle for proving the new propulsion system,
designers have taken the trouble to make its commercial pote
tialities apparent. There is ample room aboard for eight passeng
in addition to the crew of two, and plenty of volume and flo
space for freight. The cockpit has dual flying controls, which w
enable pilots to be easily initiated into the new feel of the P.7
a glazed nose has not been provided—although it will be on t
P.105—and downward vision is afforded by large D.V. pane
Two fuel tanks, of 170 Imp. gal total capacity, are housed
the keel.

Design work on the P.105, which as previously mention
represents a considerable refinement of the P.74, is in hand, a
construction of the prototype rotor has started. This ten-passeng
machine will be the first commercial interpretation of the ne
propulsion system. It may be expected to make its debut
1958, by which time a great deal of pioneering experience w
have been gained from the P.74. Of its promised merits
economy, quietness, simplicity, flexibility—the latter stands o
most prominently. Since the essence of a helicopter is its roto
engine combination, the availability of a compact and independe
unit, to which almost any kind of frame may be fitted, promi
a significant broadening of the scope of future helicopter operatio

LEADING DATA

P.74 Research Helicopter (two Napier Oryx NOr.1 turbines of 750 g.h.p.
Maximum weight, 7,750 lb; fuel capacity, 170 Imp. gal; rotor diameter, 55 ft.

P.105 General Purpose Helicopter (two Napier Oryx NOr.4 turbines
825 g.h.p.).—Maximum weight, 10,000 lb; seating capacity, two pilots and
passengers; fuel capacity, 230 Imp. gal; cruising speed, 100 m.p.h.; vertical r
of climb at loaded weight of 9,600 lb, 250ft/min; range with full payload of 2,250
165 miles at 5,000ft; rotor diameter, 63ft.

*The ultimate aim of the Hunting Percival helicopter design phi
sophy is a compact and independent rotor-engine system which perm
complete freedom of choice of the airframe. On the left is the te
passenger P.105, and on the right the "aerial crane."*