The Fairey Gyrodyne

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The Gyrodyne Approach

The success of the helicopter today is primarily the result of a background of rotary-wing experience covering many years of research into the problems of the gyroplane This simple form of rotorcraft, proposed by JUAN DE LA CIERVA, was developed to a stage at which vertical take-off and landing were normal maneouvres and were no longer exclusive features of the helicopter Only the ability to hover remained as the unique advantage of the power-operated rotor—an advantage for which a heavy penalty had to be paid The general problems of the helicopter for civil use are concerned mainly with an alleviation of the penalty that hovering has incurred

The hovering requirement had led to the use of twin contra-rotating rotors in spite of their greater complexity, to heavy disc loadings with their poor gliding performance, to rotors of high pitch which require rapid action on the part of the pilot to prevent them from stalling in the event of power failure, to complicated devices for governing rotor pitch or engine speed arising from the need for control simplification, to an excessive forward inclination of the aircraft in forward flight, and to periodic blade-tip stalling which had imposed a new limitation on top speed In other words, the ability to hover could be bought at the expense of simplicity of control, safety, compactness of design, and comfort

In the design of the Gyrodyne an attempt has been made to regain some of the ground that was lost The propulsive powered-rotor and the auto-rotative rotor represent two extreme forms of rotary-wing aircraft, and the relatively non-propulsive rotor of the Gyrodyne avoids certain limitations of the two extremes The possibilities of the Gyrodyne principle were discussed as long ago as 1940 (Ref 1) and a description of the present machine was given in a recent lecture to the Helicopter Association (Ref 2) It is proposed this afternoon, therefore, to mention only those particular features of the Gyrodyne which have a bearing on the problems discussed at the Morning Session

Compactness of Design

In several respects the Gyrodyne configuration was the forerunner of the form of helicopter developed to a practical stage by IGOR SIKORSKY Both utilise a single lifting rotor in torque balance with a single non-lifting airscrew, both have branch transmission systems of variable power distribution, and both obtain direct control in yaw from foot pedals, which vary the collective pitch of the non-lifting airscrew The manner of operation of the two is therefore much the same, the main difference being one of degree only, in regard to control response The Gyrodyne, due to its compactness of design, would be the more manoeuvrable but for the stabilising surfaces at the tail

Where the two differ in principle is in the azimuth location of the non-lifting airscrew and in its distance from the rotor axis Taking into account the many uses for helicopters, it is thought that forward flight will occupy about 95% of the total life of the aircraft An even higher percentage might apply to helicopters used only for transport Consequently, if the non-lifting airscrew is located laterally, as in the Gyrodyne, the power required for torque balance is utilised for the useful purpose of forward propulsion throughout practically the whole of the normal operating life

On the other hand, with the non-lifting airscrew located at the tail, the power applied to it is a total loss under all normal operating conditions To keep this loss at a minimum, the tail location requires a sacrifice of compactness, and this in general results in extra structural weight There is no such requirement for the Gyrodyne

Low Rotor Power

The inevitable decrease in power loading of the propeller in forward flight decreases the proportion of power delivered to the rotor as the forward speed increases As a result, the main transmission of the Gyrodyne need be fully loaded only during the take-off and landing, thereby ensuring a high margin of safety at cruising speed, the normal condition of flight of a transport helicopter

There are, of course, many uses for the helicopter where forward speed is unimportant and where the main requirement is to lift the maximum load that the available power will allow For such duties, the non-lifting airscrew of the Gyrodyne might be moved farther outboard, but this need not be overdone at the sacrifice of compactness, because the Gyrodyne rotor can have a low disc loading and thereby lift the same load for less power than a rotor of high disc loading

The relationship between the power (x) in the branch transmission of the non-lifting airscrew, per unit total power in both transmissions, and the distance (a) of the non-lifting airscrew from the rotor axis, expressed as a fraction of the radius of the rotor, is simply $x(1 + 6a) = 1$, assuming a tip speed of 660 ft /sec and a power loading of 5 for the non-lifting airscrew If a is about one-third, as in the Gyrodyne, x is also about one-third, or, in other words, two-thirds of the nett power available, after allowing for engine cooling and transmission losses, is applied to the rotor

In spite of the saving in structural weight due to compactness of design and to the lower power requirement for the main transmission, and in spite of the low disc loading and better weight-lifting performance of the Gyrodyne rotor, it may be thought that too much power is applied to the propeller in vertical flight This power, however, can be considered as a reserve, and vertical climb can be boosted temporarily whenever necessary by the relatively simple expedient of performing axial turns

Except at air displays, a helicopter need hardly ever climb vertically out of the "ground cushion" It is a much safer procedure to climb at the forward speed requiring minimum power and a steep angle of ascent at this speed is of greater importance in practice than a high rate of vertical climb For take-off at altitude, a strong "ground cushion" is an advantage and this is assured by the low disc loading of the Gyrodyne

Low Disc Loading

Unrestricted by rotor blade clearance problems, the Gyrodyne has a lower disc loading than is possible with most other forms of helicopter This gives the Gyrodyne certain advantages in both power-on and power-off flight As the extreme limit of power loading of a rotor is equal to the reciprocal of the induced velocity, and the induced loss at take-off is roughly twice the profile loss, the limiting power loading of the helicopter is almost inversely proportional to the square root of the disc loading Thus, if the disc loading of the Gyrodyne is 20% less than that of other helicopters of equal gross weight, the Gyrodyne rotor can lift the same load for 10% less power This factor is mainly responsible for the low rotor power required in the Gyrodyne, the load sustained per rotor h p probably exceeding that of any other helicopter

A similar advantage is obtained in power-off flight The low disc loading minimises the sinking speed in a glide and ensures the safety of the occupants in an emergency landing Even at night, or in a forced landing due to fog, a helicopter of low disc loading could descend and land almost vertically without disastrous results The use of pitch change for utilising the kinetic energy of the rotor for momentary hovering prior to a power-off landing should be considered as an additional safety measure in helicopters, rather than a necessary manoeuvre upon the precision of which alone the safety of the aircraft depends

There is a general impression that a low disc loading, like a low wing loading for aeroplanes, is detrimental to efficiency at cruising speed This is not necessarily so because it is not disc loading, but blade loading, that governs the profile power loss The blade loading, being the ratio of the disc loading to the solidity, can be kept relatively high by choosing a low solidity In the Gyrodyne, the solidity is only 1% per blade and the blade loading is 75 The high blade loading ensures a low profile power loss at top speed, and the low disc loading a low induced power loss when hovering

Low Pitch

There is no doubt that low disc loading and low rotor pitch contributed to the remarkable record of safety achieved by rotary-wing aircraft in the pre-helicopter era In contrast to most other helicopters, a result of the low-pitch operation of the Gyrodyne is that it can not be stalled under any condition of flight by a possible misuse of the controls

Apart from safety, low pitch has other advantages, not the least of which is its effectiveness in minimising vibration—the " bugaboo " of rotary-wing aircraft Helicopters which are rough in operation at high pitch in forward flight are usually quite smooth at the same forward speed in autorotative flight

The necessary rotor power for sustentation is absorbed in the Gyrodyne by its relatively high tip speed and, because the tip-path plane is never tilted excessively forward for propulsion, the rotor remains at low pitch over the whole speed range

Independent Propulsion

A significant feature of the Gyrodyne is its independent means of propulsion It enables both the fuselage and the tip path plane to remain substantially level under cruising conditions This attitude is not only the optimum one in regard to drag and passenger comfort, but removes what had become an important barrier to the propulsion of helicopters Periodic lift distribution in autorotative rotors had resulted in stalling of a part of the retreating blade near the root, but, in the helicopter with a forwardly-inclined rotor, periodic stalling can occur at the blade tip This is due to the relative air speed having a down-flow component Operation of the helicopter close to the periodic stall of the retreating blade is limited by vibration No matter how much power is available, therefore, it cannot be utilised for propulsion beyond the periodic tip-stall barrier

The international speed record for helicopters, now held by the Gyrodyne, can undoubtedly be exceeded in future by helicopters with propulsive

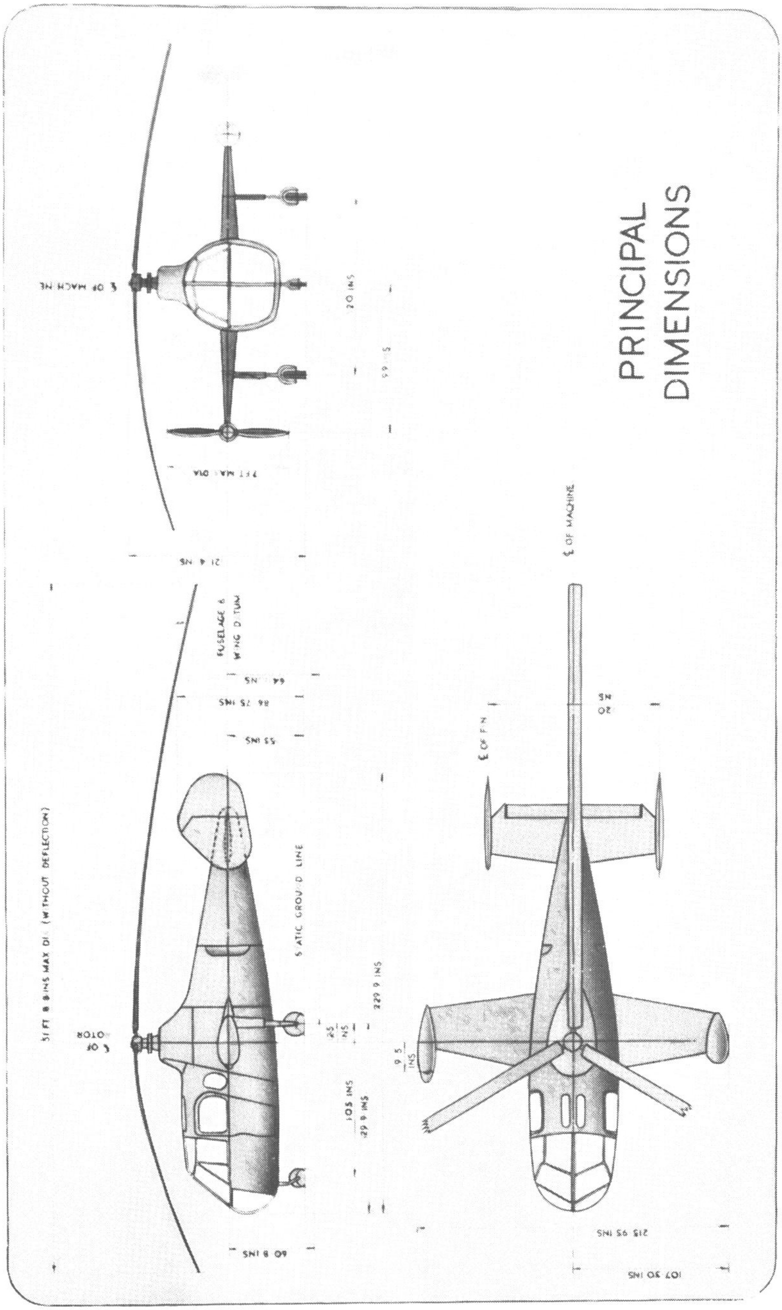

FIG 1

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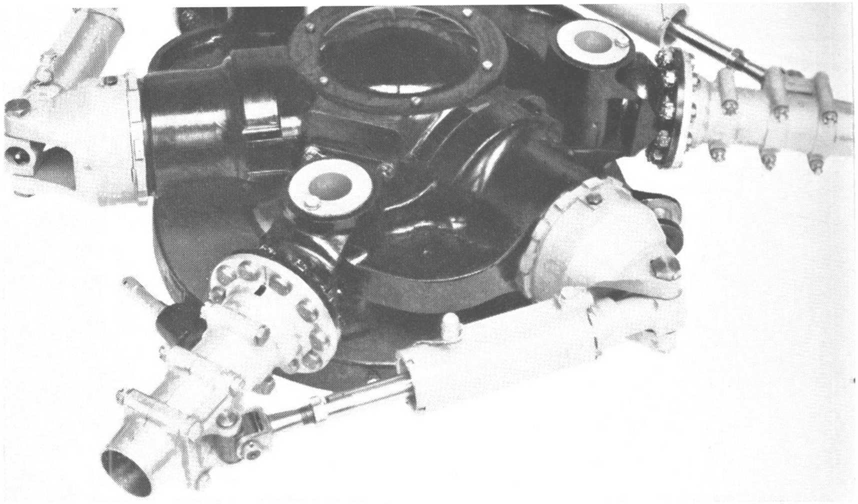


Fig 2
Rotor
Head

rotors, but, as higher-powered helicopters become available, the feature of independent propulsion as demonstrated in the Gyrodyne will become more and more essential There are many sources of vibration inherent in rotary-wing aircraft but the periodic blade-tip stall is one which can be avoided and should not now prevent a further improvement in the helicopter speed range Continuity of operation under adverse wind conditions is just as important for transport helicopters as for aeroplanes and can be ensured only by the ability to maintain a high cruising speed

Control Simplification

The simplicity of control of rotary-wing aircraft has deteriorated with the change-over from the autorotative rotor to the powered rotor The number of controls has been increased from two to four, and the ever-present necessity for torque balance and pitch-throttle synchronisation requires that the four controls be operated simultaneously The interdependence of so many controls, requiring continuous manual adjustment by the pilot, is a further penalty that has been paid for the ability to hover

In the Gyrodyne an attempt has been made to minimise this penalty by the suppression of one control There are no flight controls other than stick, throttle and rudder pedals, collective pitch change being effected automatically The required automatic change in blade angle is associated with the angular displacement of the blade in azimuth in response to torque, by giving the drag hinge a slight downward and outward inclination Thus, there is an immediate increase in manifold pressure whenever the throttle is opened without there being any appreciable change in angular speed In addition to the automatic change of collective pitch, an over-riding control, mainly for trim purposes at altitude, has been designed but is not yet installed It is proposed to utilise this also for momentary hovering prior to a power-off landing The over-riding device operates additional blade hinges which are locked in normal flight

A further penalty in the helicopter has been the introduction of blade torsional bearings for both collective and cyclic control of pitch In the Gyrodyne such bearings are eliminated entirely, and instead of a separate swash-plate for transmitting control movements from the stick to each individual blade through the necessary levers and bearings, the rotor head itself forms the swash-plate

This does not mean that the hub axis is tilted as was the usual practice with autorotative rotors Instead, the hub axis, *i e*, the axis of the main bearings, remains fixed, and the rotor head—the hub member to which the blades are attached—is tilted with respect to the hub axis Consequently, in forward flight a forward inclination of the head balances the backward inclination of the tip-path plane that results from the usual flapping motion of the blades The tip-path plane, therefore, remains substantially at right angles to the hub axis in all conditions of steady flight, which is important for minimising vibration

Safety Measures

Stick shake is completely eliminated by the use of hydraulic irreversibility Except during the first few hours of flight, the steady loads also have been suppressed hydraulically, but it is now considered more desirable to retain the steady loads, which provide a natural feel, and to use hydraulic irreversibility only for suppressing stick shake and as a precaution against misuse of the control A sudden backward movement of the stick in flight, for example, can impose on helicopters loads in excess of their design criteria

A similar possibility exists in helicopters on initial engagement of the clutch and, in the Gyrodyne, to ensure that the rotor blades can not be damaged by a sudden angular acceleration, an electrically-operated actuator is provided for controlling the rate of clutch engagement, thus limiting the maximum starting torque It is thought that a torque-limiting device should be an essential airworthiness requirement for helicopters

Transmission Features

The installation of the power plant and transmission consists of four self-contained units the Alvis engine with its mounting and cooling system, the main gearbox incorporating the clutch and freewheel in addition to the first stage reduction gears for the rotor and propeller drives , the top gear box, housing a double epicyclic gear, with a rotor brake mounted above it , and, at the outer extremity of the starboard wing, a gear box carrying the propeller reduction and pitch-changing gear The propeller is positively geared to the engine and not to the rotor

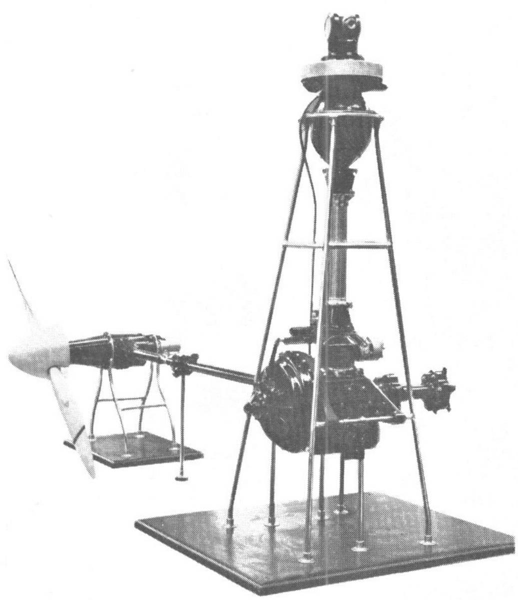
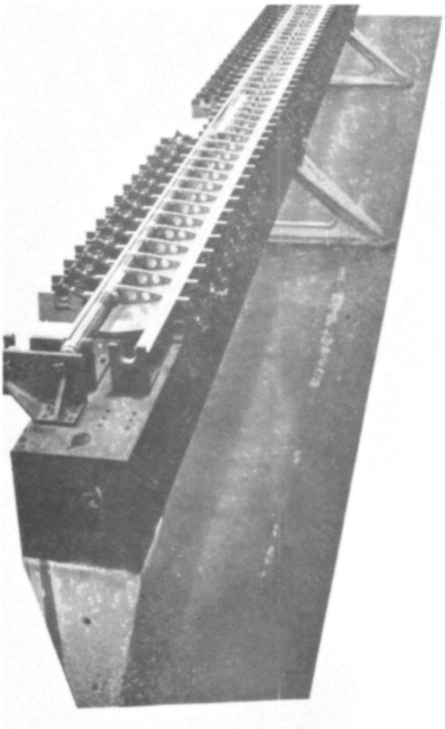


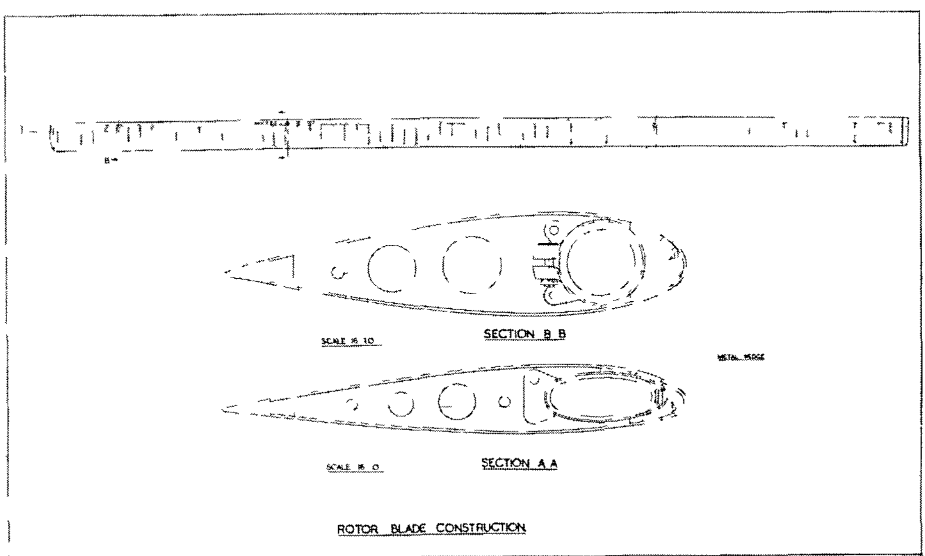
Fig 3



Freedom from Flutter and Fatigue

The rotor blades are of accentuated flexibility in bending, but rigid in torsion On no occasion has there been any sign of flutter, although a Mach number of 0 8 has been exceeded at the advancing blade tip The blades have been manufactured to close tolerances in a jig and, with this object in view, they have been given no taper or twist A stiff profile is maintained by wooden ribs and a plywood covering, a steel tubular spar being the main strength member This is circular in section at the root end, but over the greater part of its length it is of oval section A root collar integral with the spar — a Seefab development — enables the blade to be attached to the root fitting without stress concentration due to perforation of the tube Drilling of the spar is avoided also at the rib clips which are attached frictionally over the main portion of the blade

Fig 5



Strain gauge tests have been conducted in flight, and the steady and alternating stresses determined at four different stations along the blade Specimen lengths of the spar, loaded to a greater stress than the corresponding parts of the blade in flight, have been placed in a fatigue-testing machine and subjected to alternating stresses several times greater than the highest recorded in flight The spar has thus been proved to have an unlimited life

Fuselage Stabilisation

Although the present fuselage is of steel-tube construction, a metal monocoque is being provided for production The front portion is long enough to take a full-size stretcher, and as the tail portion is relatively short, side fins are required for directional stability

No attempt has been made so far to provide dynamic stability at zero forward speed The necessity for automatic stabilisation of helicopters in the hovering condition depends upon whether the aircraft will be required to hover for long periods As the Gyrodyne is designed primarily as a transport aircraft, its normal condition of flight is at cruising speed It is, therefore, under cruising conditions that stability is important and for this purpose a tail-plane is provided in addition to the side fins The stub wings, which form fairing surfaces for the structure supporting the propeller and the main legs of the tricycle undercarriage, have a stabilising effect in roll—a manoeuvre in which rotary-wing aircraft tend to be too sensitive, compared with aeroplanes, owing to the absence of fixed wings

Specific Utilisation

In any field of transport, no one device has a monopoly of all functions Each type is a solution of a particular transportation problem The advent of the helicopter, for example, does not put an end to the aeroplance, but confines its operation to uses for which it is better adapted So also every

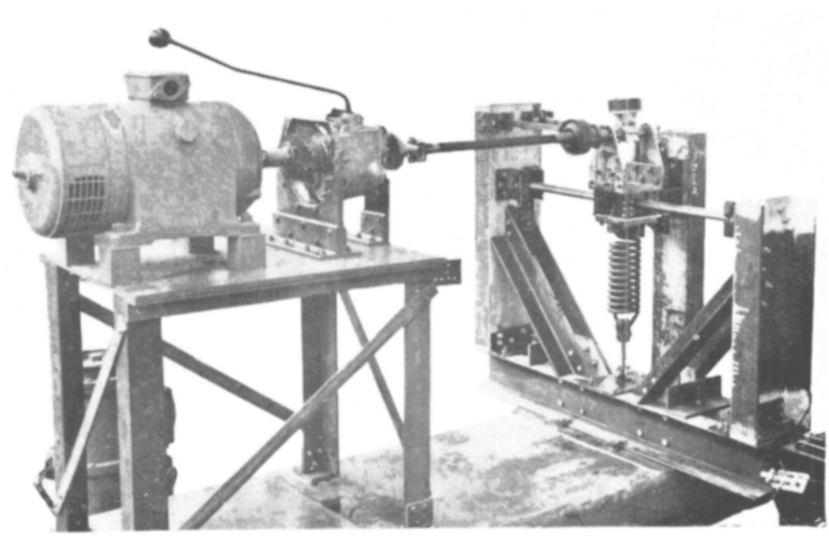


FIG 6—Rotor spar fatigue tests

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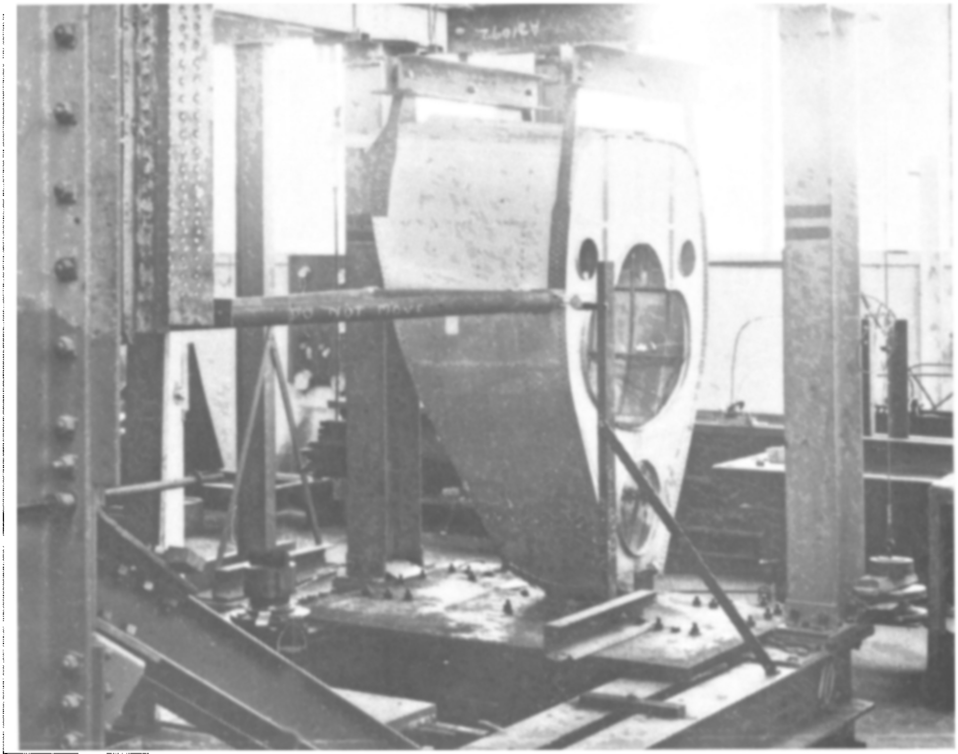

FIG 7

form of helicopter has its own specific sphere of usefulness, and the obvious one for the Gyrodyne is wherever a high cruising speed is essential, or continuity of operation is required under adverse wind conditions Thus, the Gyrodyne is best adapted for making long non-stop journeys, such as from city centre to city centre, rather than as a feeder line transport for operating only between a city centre and its adjoining airport

If the ability to hover has been combined effectively with the ability to maintain a high cruising speed, without there being an appreciable departure from the low disc-loading and low-pitch advantages of the autorotative rotor, the Gyrodyne has achieved its purpose and would appear to fulfil the general requirements of a helicopter intended for civil use

REFERENCES —
Ref 1 BENNETT, J A J *Aircraft Engineering*, January, 1940
Ref 2 BENNETT, J A J *Journal of the Helicopter Association*, July, 1948

FIG 8 —The Gyrodyne in forward flight

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THE CHAIRMAN

The second paper this afternoon is to be presented by MR R HAFNER and deals with some aspects of the Bristol Type 171 Helicopter MR HAFNER was educated at the Technical College in Vienna and has been solely engaged on rotary wing development for more than twenty years, having produced his first helicopter design in 1927 He came to England in the early 30's and continued with helicopter development and then turned his attention to the design and construction of a gyroplane which was known as the A R 3 and which aircraft proved to be very efficient and pleasant to fly

During the early part of the late war, he collaborated with DR BENNETT on various rotary wing projects under the M A P , and joined the Bristol Aeroplane Co , as Chief Designer of the Helicopter Division in 1944 in which capacity he is entirely responsible for the design of the Bristol 171 I can speak at first hand of the excellent qualities of this aircraft having been privileged to carry out the first few hours of the prototype flying I now ask Mr Hafner to present his paper

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The Bristol 171 Helicopter

By RAOUL HAFNER

The technical problems confronting the helicopter designer are very clearly enumerated in Captain LIPTROT's paper, and Wing Commander BRIE has drawn attention to a number of considerations of importance to the operator

With some of these problems I have dealt in an earlier paper(1), and in order to avoid repetition I propose to leave out from this discussion points which have already been raised

VIBRATION

Rotating-wing aircraft in forward flight are subject to vibrations for reasons which are fundamental and we must not therefore expect the elimination of these symptoms but only their reduction to generally tolerable proportions We need, therefore, more accurate methods of recording and analysing vibrations in helicopters in terms of component frequencies and amplitudes, and in addition we must have generally agreed standards for comfort, *i e* , limiting vibration levels as a yardstick both to makers and users of these aircraft

As to the causes of rotor vibrations there is in the first instance a change of velocity with blade azimuth the maximum being at the advancing and the minimum at the retreating side of the rotor orbit, and secondly a change of inflow angle with blade azimuth due to the coning of the rotor blade and the curvature of the airflow in the vicinity of the rotor, the maximum being aft and the minimum forward of the rotor centre Therefore, in order to maintain a constant rotor thrust (or constant blade lift) during rotation, which is one of the essentials for freedom from vibration, the blade incidence must be varied in a cyclic manner Because the factors governing blade feathering are complex, the feathering motion cannot be expressed mathematically in a simple form but only by an infinite Fourier series * Typical values for