The Technical Point of View

By Captain R N LIPTROT, C B E , B A (Cantab)

In a paper such as this, where I am asked to point a critical finger at the problems which we have to face in developing the helicopter for civil operation, it is inevitable that I should call attention to the shortcomings of the helicopters on which our experience rests so far We have to remember that it is only a few short years since the helicopter reached the stage when it could be put in the hands of operators, and that the types on which the whole of our experience is based were born in the stress of the war years when they had to be put into use just as soon as they worked reasonably well We have to admit that in many respects they are relatively crude in design, but, nonetheless, they have demonstrated that the helicopter is a practical transport vehicle and they have proved their worth in many fields The helicopter has definitely arrived and will take its place in Civil Aviation as complementary to the fixed wing aeroplane for normal transport operations, and in a sphere entirely its own where its special characteristics make it capable of doing work which no other vehicle can perform

When we critically examine the helicopter problem and the characteristics of available types, the special problems which stand out for investigation during the next stage of development are as follows

Vibration

The least informed on the subject will immediately realise that when the rotating lifting system of a helicopter is in translation, the velocities and, therefore, the lift on the blades on the advancing and retreating sides are very different, so that in the absence of some special arrangement there would be an upsetting couple about the longitudinal axis This can only be corrected by a periodic change of the lift and drag forces on the blades, so we can expect to experience severe vibration

The classic solution, of course, is the flapping blade introduced by Don Juan de la Cierva, which not only balances out the dissymmetry of lift, but relieves the blade roots of the periodic bending moments This solution was elegant, but, unfortunately, instead of relieving the vibration problem, it actually accentuates it This arises in several ways

(*a*) The longitudinal flapping due to the forward motion results in a tilt of the tip path plane with respect to the axis of rotation and, in addition, the tip path plane has to be tilted by some form of periodic control in order to trim the aircraft at the attitude necessary for the speed There is, therefore, a dissymmetry in the plane at right-angles to the axis of rotation and periodic forces in that plane

(*b*) In addition, a flapping blade is subject to a Coriolis acceleration in the plane of rotation Perhaps the simplest way of explaining this is to point out that, as a blade flaps upwards, the distance of the centre of mass from the axis of rotation decreases For constant Kinetic Energy however, the product of this distance times the angular velocity must

https://doi.org/10.1017/S2753447200000470 Published online by Cambridge University Press

remain constant, so that the blade in effect must accelerate as it flaps upwards and decelerate as it flaps downwards This again involves periodic forces in the plane of rotation

These two dissymmetries make it necessary to introduce a drag hinge, in order to relieve the blade root from the periodic bending moments which otherwise would tend to cause blade fatigue failure The introduction of the drag hinge, however, leads us into further trouble, since the natural frequency of one of the modes of oscillation of the blade about the drag hinge is close to that of the periodic forces, so that we get an unstable hunting oscillation unless the freedom of movement of the blade about the drag hinge is restricted by damping or the natural frequency is raised by some means

(*c*) As the ratio of forward speed to rotational speed increases, the retreating blade is more and more stalled, and for this reason again vibration is experienced

(*d*) In the helicopter, where forward motion is obtained by tilting the tip path plane, there is an added axial flow through the disc, which reduces the effective angle of attack of the blades The tip sections are affected less than the root sections, so that as the collective pitch is increased to maintain the average lift at the required value, the tip sections are overpitched and periodic stalling occurs

Enough has been said to show that in forward flight we have a veritable witch's cauldron of fluctuating forces and a vibration problem which, though it may delight the heart of a vibration engineer, is one of the main headaches for the poor designer Vibration indeed, rather than compressibility effects, may be the major factor in limiting the top speed of helicopters

It is not within my province to indicate the lines of attack on this problem, that is for the aforementioned poor designer this afternoon, but I do want to introduce a word of warning Some designers have considered that it is sufficient if the vibration is isolated from the aircraft, arguing that what the eye does not see—or rather what the body does not feel—the heart does not grieve about This, of course, may be quite all right for the passenger who would not tolerate severe vibration, but it is simulating the ostrich in burying one's head in the sands of complacency Even though isolated and, therefore, not impinging on one's senses, the periodic forces are still there and will promote fatigue failure Personally, as one who persists in flying helicopters, I want to feel any vibration which may be present, so that should it increase in severity I know that something is wrong and can take steps to correct it

Simplification of Control

There is a widespread belief that the helicopter is difficult to fly, and we have all heard of pilots with thousands of hours on fixed wing aircraft who, in the early days of their conversion to the helicopter, have despaired, of ever getting the hang of the thing It is perfectly true that existing helicopters prove to be extremely difficult to master in the case of some pilots It is probably true to say that it is far easier to train an *ab initio* pupil, who has never been in the air before, than a very experienced fixed wing pilot This in part is due to a psychological effect, in that the skilled pilot at first cannot bring himself to break all the rules of the game on which his very life depends on a conventional aircraft, for instance, in flying at maximum speed and deliberately coming to a standstill when some 20 ft above the ground

This aspect is well illustrated by a comment which was made during the first delivery flight of the Sikorsky XR–4 from Bridgeport to Wright Field After landing at Rochester and doing some typical helicopter flying, one of the flying instructors on the field approached the pilot, saying " How do you expect us to teach these fledgelings to be good fliers? We spend months teaching them to keep flying speed at all times, and then you guys come along and make liars out of us with that cockeyed contraption Doesn't the Army want pilots?" The remaining difficulty arises from the control characteristics of the helicopter

In the fixed wing aircraft, although it has the six degrees of freedom of any body in space, we can get complete control from three angular controls and the throttle, since the aircraft can only move, at least continuously, in the direction in which its nose is pointed The helicopter, however, as our American friends put it, can move in 362 directions, *i e*, along any azimuth as well as up and down along its axis At least one additional control, therefore, is required—the collective pitch control As the human being only has two hands and two feet, two of these controls, the throttle and the collective pitch have commonly been operated by one hand, and it has been the correct co-ordination of these two which has complicated the issue for the pilot On top of this, in what has become the classic configuration, *i e*, the single main rotor with tail rotor for torque compensation, there is a further difficulty that any use of one control demands co-ordinated adjustment of other controls , for instance, use of the tail rotor as a yawing control absorbs more power when turning against the torque reaction than with it, so that an appropriate throttle adjustment has to be made if height is to be maintained Conversely, any adjustment to the throttle or collective pitch alters the torque reaction and so involves the use of yawing control In sideways flight opposite rudder must be applied to keep the aircraft heading correctly, and this again involves throttle and/or pitch correction to maintain height

Again there is a lag in response to azimuth control, though the control is extremely powerful and requires only very small application, and the response is normally far quicker in the rolling sense than in the pitching sense due to the big differences in inertia about the two axes For this reason the pilot tends to overcorrect and to start violent swings which can result in an accident when flying close to the ground

I have made something of a song about this difficulty of control because it is very real, but I would stress that it is only in the early stages that there is any real difficulty in control Once the pilot gets the hang of the thing he can relax a little and flying becomes relatively simple Nonetheless, flying helicopters demands a good deal of concentration, and in the next generation of helicopters the controls must be simplified and some of the co-ordination of the controls must be done for the pilot by some mechanical device in order to relieve the fatigue which today is quite severe

Stability

Mr Stewart in his lecture gave a very full account of this problem, so that I need not go into detail It will suffice if I say that, with the increasing use of the helicopter for commercial operation, we must be able to cater for more and more adverse weather conditions This is especially important for any of those uses where a rigid time schedule is demanded, as, for instance, for postal services Intrinsically, the helicopter is the safest of all flying machines under low visibility conditions, since it can adjust its speed to be appropriate to the visibility at the time Under blind conditions, however, where the pilot has to give his whole attention to navigation, radio, contacts with controls, etc , stability characteristics which might be acceptable under contact conditions even in low visibility become quite intolerable Moreover, we can expect increasing use of the helicopter by private owners and others who cannot be given an aircraft with undesirable handling qualities, even though such poor qualities might be overlooked to some extent by skilled operators or for purely military use

It is important, therefore, that the designers should give us improved stability, certainly under normal cruising conditions, and preferably under any conditions of flight, including hovering

Safety

The helicopter in common with the gyroplane is the safest of all aircraft, since it cannot be stalled in the ordinary sense of that term Even though its speed is inadvertently reduced right down to zero, it will sink on a level keel under full control In the event of power failure, it is converted to a gyroplane by pitch reduction and it can then make a safe forced landing into a small clear space exactly like the Autogiro I realise that in making such a sweeping statement as this I am likely to be criticised, but I make the statement deliberately in order to stimulate discussion and get the answers from the designers

There is, however, the difference in the helicopter that, in order to ensure the maintenance of r p m , the blade pitch must be reduced rapidly, otherwise, with the blade angles commonly necessary in ordinary flight, the rotor would slow up below the safety line in a few seconds It is for this reason, coupled with the need to simplify the co-ordination of pitch and throttle, that some form of constant speed unit has been advocated, so that in the event of power unit failure the change to autorotation is immediate and automatic, and does not require any emergency action on the part of the pilot

A word of warning is perhaps necessary on constant speed devices Most of the devices proposed so far follow the lines of the constant speed propeller, *i e*, the governor operates direct on collective pitch These devices are not satisfactory, since they introduce a hazard of their own in that, in the event of power unit failure very close to the ground, they take the wrong remedial action, since, under these conditions, the collective pitch should be increased, so using the kinetic energy of the rotor to arrest the landing, and as the pilot himself has no control over collective pitch he himself cannot take the right corrective action On the other hand, if the governor operates on the throttle while co-ordination of pitch and throttle is done automatically for the pilot, the collective pitch lever becomes his master control and he still has to decrease pitch manually in the event of engine failure

There is a further difficulty that, in the helicopter state, the airflow is downwards through the disc from above, whereas in the autorotative state it is upwards through the disc Also, if the engine failure occurs at slow air speeds, it is necessary to pick up speed in order to obtain the minimum rate of descent on the glide To pick up the necessary air speed from hovering and to establish the new flow pattern, the average loss of height is of the order of 300 ft, decreasing with increase in air speed at the time of the engine failure This is the one real potential hazard with the helicopter, and today pilots are instructed not to fly at low speed between, say, 30 ft and 300 ft

If the single-engined helicopter is to be permitted to operate over built-up areas, it will be essential to remove this potential danger and, in any event, it will have to be catered for, since so many of the practical uses to which the helicopter can be put—for instance, crop spraying—demand flight at low speed, even hovering, and at relatively low heights

Maintenance

I think that nobody with operating experience on the available helicopters will disagree with me when I say that it is not the admittedly high initial cost of the helicopter today which has taken the gilt off what looked like a gingerbread to the early helicopter operators, it is the maintenance costs due to the direct labour in short period inspection and overhaul, the excessive requirements of replacement parts, and the lost time due to unserviceability, which have damped the ardour of the most enthusiastic It is true that maintenance crews with their built-up experience have made great advances in more rapid maintenance and servicing technique, but the costs have stabilised at too high a level

Frequent dismantling and inspection to preserve airworthiness and smooth operation were well worthwhile when we were gaining experience, but that time has now been passed over, and in far too many existing designs when undertaking this work the maintenance crew is faced with an exceedingly complicated mechanism which is over expensive to take down and inspect, if only by reason of the sheer number of parts involved For example, in transmitting the cyclic pitch control from a swashplate to the blades, too many parts are used A very small amount of wear at each joint causes an overall amount of backlash in the system, which involves early scrapping of many parts This motion could far better have been transmitted by a single link, increasing the life between overhauls and cutting down expensive replacements

Ball or roller bearings at heavily loaded flapping, drag and feathering hinges are a source of continual trouble due to friction oxidation (the so-called " False Brinnelling ") which occurs in bearings where the angular movement is small Friction oxidation causes very short bearing life as compared with a normal fatigue failure of the same bearing for single direction continuous motion, and it is only by reducing the load rating to about one-third of the unidirectional rotating rating that one can get a satisfactory life in the applications which we are now considering This phenomenon, although known already in many industries, has not been realised generally by the helicopter designers, who have chosen their bearings on the makers normal ratings and, as a result, bearing replacement has been one of the major causes of high maintenance costs Similar early failure of universal joints at points where angular change in direction of shafting is only one or two degrees was a fruitful cause of unserviceability and need for replacements in the early operational helicopters Research on this phenomenon and the development of bearings which will give longer life under oscillating motion at small amplitude is urgently needed for the helicopter

Most helicopters are characterised by the complete inaccessibility of their power plants Engines are enclosed in cooling air ducts, completely boxed in by fire-walls and close to fuel and oil tanks in such a way that they can hardly be seen even by the most conscientious mechanic, and so receive little or no preventative maintenance Cases are known where the fuel tanks have to be removed to enable the plugs to be cleaned The designer all too often in the past has been responsible for an arrangement in which the aircraft virtually has to be dismantled in order to change the engine Maintenance under such conditions is naturally difficult and the designer must do better in the future

---

Discussion

W Tye (Air Registration Board) On the general layout of rotor systems in present-day helicopters, Mr HAFNER would probably say why it was best to react the main rotor torque with a little fan stuck several feet behind where any decent fuselage ordinarily stopped , Dr BENNETT would then explain why the same function was so much better performed by a propeller asymmetrically mounted , and Mr SHAPIRO might even try to convince the meeting that both these solutions were wrong, and that the real answer was to suspend the helicopter from three remote corners Perhaps the problem was comparable with one debated many years ago on monoplanes, biplanes or triplanes, and whether the tail should be in front or behind He did not know who was right or who was wrong about the helicopter, but insofar as any residual engineering instincts were left to him, these instincts rebelled against all these configurations His instincts did not tell him what a helicopter should look like, but he hoped that someone might supply the answer He admitted that these criticisms might be quite unjustified

They were at the beginning of the development of the helicopter into a sound commercial vehicle, but if helicopters were to be made commercial vehicles, they must be more efficient (in the broadest sense), and safety, which had so far been good, must keep pace with the increasing uses of the helicopter

The authors had referred already to a number of directions in which improvements could be achieved, both in efficiency and safety These two developments must proceed hand in hand, although, inevitably they would pull in opposite directions The aim of airworthiness people was to see that a reasonable balance was maintained between the two

The problem was by no means new, for it had to be faced every day with fixed wing aircraft, but in that latter sphere they had many years of experience to guide them In the helicopter field the experience was much shorter, and he felt it would be easy to allow safety to suffer in the interests of efficiency, or vice versa The only satisfactory answer was to obtain as much information and as quickly as possible about the way in which helicopters behaved in operations or simulated operations

The following were examples of things they needed to know —

The loads applied by the pilots in manoeuvres , Information to assist in the determination of fatigue conditions for rotor blade design , The velocities of descent in normal and emergency landings , The use of engine power in typical flights , The effect, if any, of ice on the rotor blade , The degree of stability necessary for safety

That list was not intended to be exhaustive

He had served on the Air Registration Board's Rotorcraft Requirements Co-ordination Committee, on which designers, engine constructors, operators, and specialists from the R A E and the Ministry of Supply were striving to prepare a design code which would establish and maintain a reasonable level of safety The Committee's task was made extremely difficult by the absence of the kind of information to which he had referred

https://doi.org/10.1017/S2753447200000470 Published online by Cambridge University Press