THE HELICOPTER

Part II—Power and Lift : Flight Control and its Relation to Hub Design

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This is the second of a series of articles specially commissioned from Capt. Liptrot, formerly Deputy Director of Helicopter Research and Development, Ministry of Supply. In the first instalment, published last week, he briefly recalled the history of the helicopter and explained its basic principles of operation; in the present contribution he discusses, among other aspects of his subject, present-day control systems and rotor-hub design.

IT is not appropriate to go into helicopter theory at any length in an article such as this, but the reader will wish to have some indication of the weight which can be lifted per horse-power. This can be stated quite simply. The thrust of a helicopter rotor when hovering, like that of an ordinary airscrew, is due to the air being accelerated on passing through the rotor disc, the thrust being equal to the momentum imparted per second. The momentum theory of airscrews shows that the added velocity of the air in passing through the disc is related to the disc loading (weight carried per square foot of the disc swept by the blades) by the equation $v=14.5\sqrt{\text{disc loading}}$, lb/sq ft. If there were no losses, the power which would be absorbed by a rotor supporting a gross weight W would be $\text{h.p.}=\frac{Wv}{550}$

Hence in the ideal rotor the weight lifted would be

$$\frac{W}{\text{h.p.}}=\frac{38}{\sqrt{\text{disc loading}}}\ \text{lb/h.p.}$$

In a practical rotor, however, the distribution of lift over the length of the blades is not uniform, as assumed in the simple theory; the blades, like any other aerofoils, have drag and require power to drive them, and there are other losses such as the rotational energy in the slipstream. When all these are taken into account the weight per horsepower which can be lifted vertically is reduced to approximately

$$\frac{W}{\text{h.p.}}=\frac{25}{\sqrt{\text{disc loading}}}\ \text{lb/h.p.}$$

An important point to note about the helicopter is that even though overloaded to the point when it can only just hover, it can still fly at appreciable heights if it is given forward speed. The limiting power-loading in forward flight is, indeed, nearly double that at hovering: the speed at which the power required is a minimum is, with current rotor characteristics, about 60 m.p.h. If, then, the overloaded helicopter can hover just above the ground, it can be accelerated up to this minimum power speed and can then climb away.

This power of taking off when vertically overloaded is increased by the so-called "ground cushion." Within a distance of the rotor from the ground roughly equal to its own radius, the lifting capacity of a rotor is increased by some 20 per cent as compared with its lift outside the cushion.

How a Helicopter is Controlled.—In the fixed-wing aircraft, though it has the six degrees of freedom of any body in space (that is, linear movement along, and angular rotation about, its three principal axes) we can get complete control from three angular movements and the throttle, because such aircraft, at any rate continuously, can move only in the direction of the longitudinal axis. The helicopter, however—as the Americans so graphically put it—can move in 362 directions, i.e., in any compass direction, irrespective of where its nose is pointing, and also up and down along the rotor axis. Therefore, at least one other control—the collective-pitch control—is necessary. The four necessary controls can now be discussed.

(a) **Collective Pitch.**—The lift of a helicopter rotor depends on the local angle of attack of the blades (the cross-sections of which are of aerofoil shape, as in the ordinary airscrew) and on the square of the relative air velocity at each blade section. The local angle of attack depends on the geometrical setting of the blade and on the resultant airflow across it; this flow, as in the airscrew, is the resultant of the rotational speed of the induced flow on which the development of thrust depends, and of any flow due to the velocity of the helicopter. The pilot, therefore, must have some control over the basic setting of all the blades (collective-pitch control, as its name implies) in order to:—

(i) vary the power required by the rotor independently of rotational speed;
(ii) compensate for the changes in the effective angle of attack of the blades due to variations in the axial flow through the rotor disc with speed;
(iii) compensate for the change in air density with altitude.

Normally, in the commonest system, the pilot is given the necessary control over the blade angles, and therefore over the rotor thrust, by a separate lever—the collective-pitch lever. As the blade angles are increased the profile drag of the blades increases and more power is required to maintain the rotational speed. This requires close co-ordination between collective-pitch and throttle settings, and to simplify matters for the pilot the two are commonly interconnected through a suitably shaped cam device, so that increasing pitch automatically increases the throttle opening, and *vice versa*. For fine correction, a twist-grip throttle is usually fitted at the end of the collective-pitch lever, so as to permit independent and over-riding control against the automatic adjustment.

Some designers have used a governor very similar to that of a variable-pitch, constant-speed airscrew so that the r.p.m. could be pre-selected, and the governor would change the blade angles to maintain the chosen r.p.m. as the throttle was opened and closed. In this arrangement the pilot's independent collective-pitch control was dispensed with and the throttle became the master control. In another arrangement the collective-pitch control is retained and a governor maintains the throttle at the correct setting.

Methods retaining the independent control are to be preferred, since the pilot has direct control over pitch at all times, so facilitating its correct use in manœuvre, and in particular in emergency—as, for instance, in the case of total loss of power, when an autorotative landing has to be made. In such a case it is still possible to touch down with substantially zero vertical velocity by increasing pitch when close to the ground, and using the kinetic energy of the rotor to make a helicopter-type landing just as though power were available.

(b) *Control Stick.*—In almost all helicopters flying today the blades are of the articulated type, and control is almost invariably by what is called "cyclic-pitch control." In this type, the control stick, by tilting a swashplate, or