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AUTOROTATION OF COAXIAL HELICOPTERS

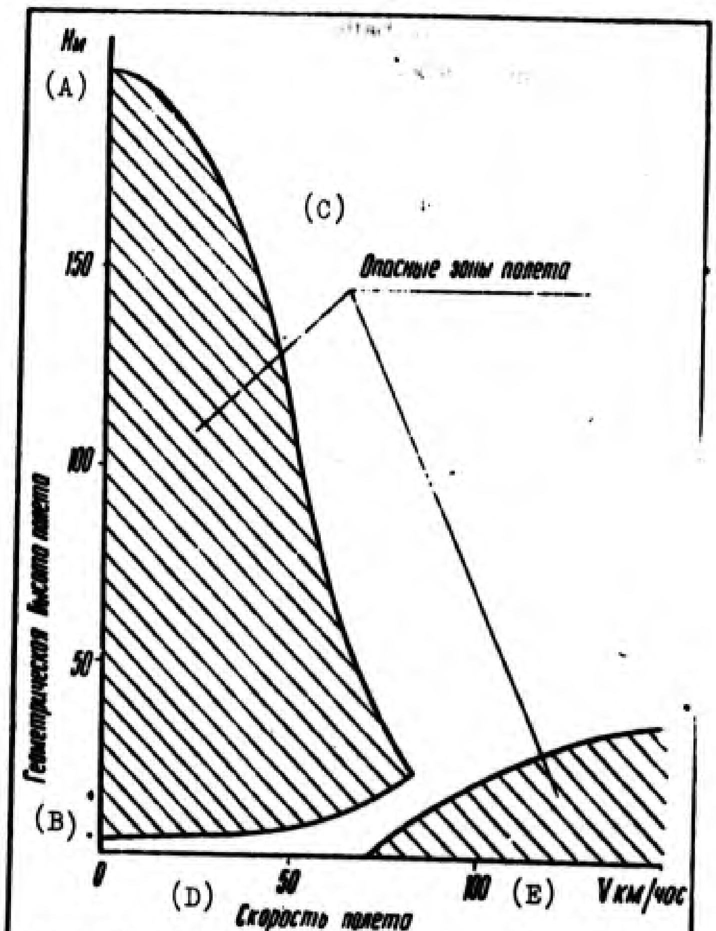
by I. Grigor'yev,
Engineer

The behavior of coaxial helicopters in the steady autorotation regime, assuming correct pilot actions, is almost the same as the usual behavior in powered flight regimes. Pilots often use this regime for descending with functionable engines (the transmission having been switched off). In steady autorotation, forward motion along the flight path is produced by the projection of the helicopter's weight to the tangent to the flight path. And the projection of the weight to the normal to the flight path is equalized by the component of total lift produced by the main rotors.

The thrust on the main rotors during autorotation results from using the power obtained from the airflow due to the descent. It is induced by the action of gravity, that is, the potential energy which a helicopter has when flying at an altitude.

In contrast to horizontal flight and in climbing when the airflow is incident on the rotors at a negative angle of attack (from above), in the autorotation regime the airflow strikes them at a positive angle of attack (from below). This produces an additional change in the angles of attack of the blade sections and leads to a situation in which obtaining the same thrust at the rotors with constant rpm and flight speed means that the design collective pitch must be considerably less than in horizontal flight, especially in climbing.

The main rotors can autorotate throughout the flight range. However in flying practice there is no necessity to execute autorotation at low and maximum velocities. As a rule, a major vertical descent occurs in these cases, which leads to complications in piloting techniques. Therefore, steady autorotation at low and maximum velocities is forbidden. Steady autorotation usually occurs in the velocity range at which vertical descent that is the minimum for the given helicopter is obtained. For transition to the autorotation regime in this flight speed range, we must have some altitude reserve, which depends on flight speed. Fig. 2 shows the typical



(F) Рис. 1. Безопасные геометрические высоты полета в зависимости от скорости.

KEY: A -- H, meters
B -- Geometric height of flight
C -- Hazardous flight zones
D -- Flight speed
E -- V, km/hr
F -- Fig. 1. Safe geometric flight heights as a function of velocity

appearance of the zones in which safe transition to autorotation is not assured for a one-engine helicopter.

The hazardous zone at low velocities is due to the insufficient power available to the helicopter for a safe landing. As the load on the area swept by the rotors is increased, the zone becomes wider. And its upper bound rises, while its lower bound dips somewhat and extends to higher flight velocities. As the load on the swept area is reduced, the hazardous zone narrows. The reduction in the size of this zone is especially appreciable for a helicopter with two engines in the event that one of them malfunctions. This occurs owing to the dipping of its upper bound and the reduction of the dangerous velocities. The lower bound for a twin-engine helicopter with given disk loading remains practically unchanged. At low altitudes and high velocities, the danger zones are formed because in the event of sudden engine breakdown there is insufficient time to take the necessary measures. But danger zones form the allowable takeoff range of velocities and altitudes.

The rpm in the steady autorotation regime is regulated by the pilot, using the collective pitch lever. Pushing the lever down increases the rpm of the main rotors, and raising it reduces the rpm. It is dangerous to allow the rpm of the rotors to drop below a certain value, since this can lead to flow separation from the rotors and an inacceptably large Mach number for the blades. So in the event of power plant failure, the pilot must immediately take measures to preserve rotor rpm.

If the switching off of engines on a coaxial helicopter occurs at a velocity greater than that recommended for rotation, then first of all the control stick must be pulled pilot-ward. This leads to a reduction in the flight speed and to an increase in the angle of attack, which blocks a decrease in the rpm. Then, as soon as the helicopter lifts its nose, the pitch must be vigorously feathered.

We must remember that in currently operating coaxial helicopters collective feathering in the event of power plant failure at high velocities without the control stick being pulled pilot-ward does in fact preserve the rpm, but still leads to steep diving. This not only increases the airspeed along the flight path, but also the vertical descent rate. Keeping the helicopter from reaching an intolerable increase in velocity will be involved, since the required shifting of the control stick pilot-ward can mean buffeting of the overhang limiting stops (especially when forward centering is used. Domestic single-rotor helicopters do not dive steeply, since during feathering the angle of stabilizer placement is reduced, owing to which a pitch-up moment is induced, capable of increasing the angle of attack and damping the velocity. If the engine cutout occurred at a velocity smaller than the autorotational speed, then maintaining rpm necessitates rapid collective feathering and restoring the helicopter to the recommended air speeds.

The presence of a flap-regulator angle somewhat promotes the transition to the autorotation regime, since the drop in the rotor rpm occurring when the engines are turned off leads to a reduction in the centrifugal forces of the blades, and this means an increase in the taper angle. As a result, the flap regulator reduces the angle of blade placement which is required to maintain the rpm. However, in the case of allowable decrease in rotor rpm the flap regulator reduces the collective pitch only slightly.

Prior to landing, in coaxial helicopters there is the option of reducing the vertical rate of descent by using the kinetic energy of the helicopter and the rotating blades of the main rotors. To this end, pilots execute a maneuver in which immediately prior to touchdown the angle of attack and the collective pitch of the main rotors are sharply increased.

An increase in the angle of attack of the main rotors results in a rise not only in the rotor drag, braking the craft, but also an increase in the lift, which slows the vertical rate of descent. The kinetic energy of the helicopter which it loses during deceleration is utilized to produce these forces. Raising the collective pitch lever also increases rotor thrust. In this case, now the kinetic energy of the rotating blades is used. As this takes place, the rotor rpm slows down, which is not dangerous, since the helicopter is already on the ground at the moment of the sharp slowdown of the rotor rpm. For fuller use of the kinetic energy of the blades, it is helpful to overspeed the main rotors within allowable limits, prior to increasing the pitch.

Yaw control of coaxial helicopters designed by N. I. Kamov is executed by cyclic change in the pitch of the main rotors and by deflecting the rudder. In this case, the deflection of the pedals increases the collective pitch of one rotor by the angle $\Delta\varphi$ and reduces it in the other by the same angle. This change in pitch results in one of the rotors becoming loaded and the other becoming lightened -- their torsional and reactive moments are changed. The difference in the reactive moments that is induced turns the helicopter in the direction of rotation of the rotor that has the smaller torque. We must note that owing to the coupling between the main rotors through the transmission, the difference in the reactive moments of the rotors will be transmitted to the airframe of the coaxial cable completely not only in powered flight, but also in autorotation regimes*.

Let us consider the effect of flight regimes on the difference in rotor reactive moments. To simplify, we will take not the difference of the reactive moments of the coaxial rotors when there is cyclic variation in pitch by the amount $\Delta\varphi$, but the difference in torsional moments equivalent to it when the angle of blade placement of a single rotor is changed by $2\Delta\varphi$, obtained by the increase and by the decrease in the angle by the quantity $\Delta\varphi$ from the initial value. Fig. 2 gives the torques of a single rotor as functions of the collective pitch angle for angles of attack corresponding to regimes of horizontal flight, climbing, and autorotation. The same figure also shows the differences in torsional (reactive) moments obtained by changing the angles of placement by the amount $2\Delta\varphi$. From the figure it is clear that the difference in the torsional (reactive) moments depends strongly on the flight regime. The same change in cyclic pitch induces during climbing and horizontal flight a much larger difference in reactive moments than in the autorotation regime. In other words, the effectiveness of yaw control via cyclic pitch change increases with reduction in the angle of attack and with increase in collective pitch, and this effectiveness decreases with increase in angle of attack and with reduction in collective

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* In single-rotor helicopters, the reactive moment in regimes of unpowered flight transmitted from the main rotors to the airframe is restricted to the sum of moments in the drive of the various installations and the friction in the transmission.

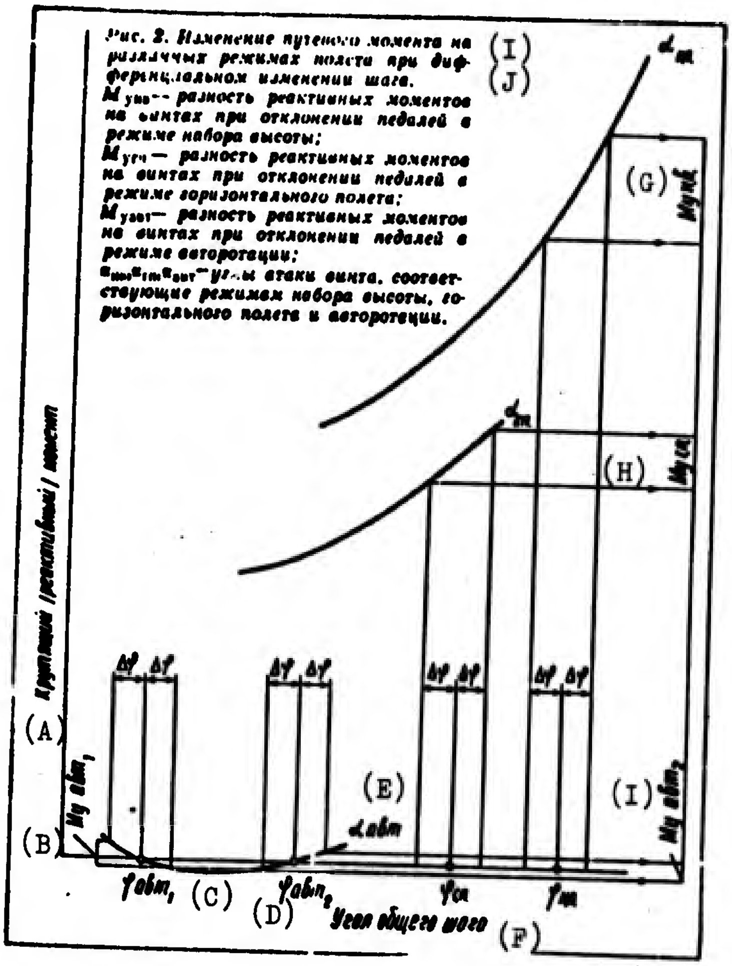

Рис. 2. Изменение путевого момента на различных режимах полета при дифференциальном изменении шага.
$M_{y нв}$ — разность реактивных моментов на винтах при отклонении педалей в режиме набора высоты;
$M_{y гп}$ — разность реактивных моментов на винтах при отклонении педалей в режиме горизонтального полета;
$M_{y авт}$ — разность реактивных моментов на винтах при отклонении педалей в режиме авторотации;
$\alpha_{нв}$, $\alpha_{гп}$, $\alpha_{авт}$ — углы атаки винта, соответствующие режимам набора высоты, горизонтального полета и авторотации.

KEY: A -- Torque (thrust) moment
B -- $M_{y\text{-auto}_1}$
C -- φ_{auto_1}
D -- φ_{auto_2}
E -- φ_{auto}
F -- Angle of total pitch
G -- $M_{y\text{-climb}}$
H -- $M_{y\text{-hor}}$
I -- $M_{y\text{-auto}_2}$
J -- Fig. 2. Change of yawing moment for different flight regimes with differential pitch change
$M_{y\text{-climb}}$ = difference of thrust moments on blades when pedals are deflected in the climb regime
$M_{y\text{-hor.}}$ = difference of thrust moments when pedals are deflected in the horizontal flight regime
$M_{y\text{-auto}}$ = difference of thrust moments when pedals are deflected in the autorotation regime
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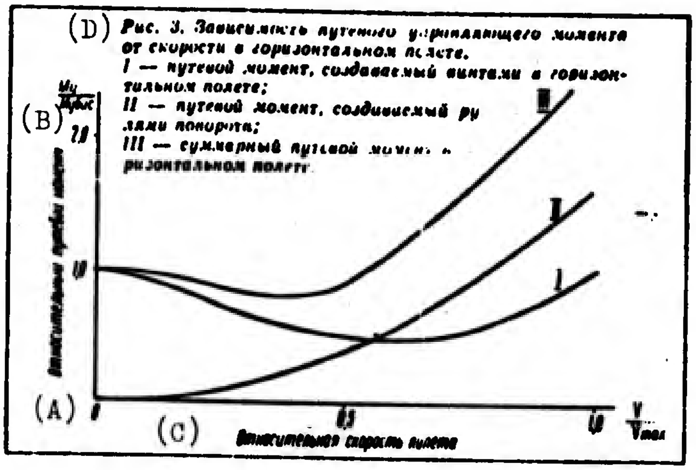
J -- /continued/

φ_{climb}, φ_{hor}, and φ_{auto} = angles corresponding to regimes of climb, horizontal flight, and autorotation



KEY: A -- Relative yawing moment

B -- $M_y/M_{y\text{-}hov}$

C -- Relative flight speed

D -- Fig. 3. Control yawing moment as a function of velocity in horizontal flight.

I -- yawing moment produced by rotors in horizontal flight

II -- yawing moment produced by rudders

III -- overall yawing moment in horizontal flight

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The figure shows that in contrast to powered flight regimes and autorotation with large pitch, for autorotation with small pitch the increase in the blade placement angle results not in an increase in the torque of the main rotor, but in its reduction. This leads to reversal of yaw control of rotors for autorotation with small pitch. In reversing, the deflection of the right pedal the moment at the rotor to the left, and vice versa. Studies showed that the reversal of the yaw control of main rotors begins to become evident as a function of the rotor rpm at different velocities: the larger the main rotor rpm, the lower the velocity at which reversal sets in.

To obtain satisfactory yaw controllability during autorotation, the rudder -- which is coupled with cyclic rotor pitch -- is actuated on a coaxial helicopter. Deflection of the rudder via pedals in forward flight induces a side force on the tail, which due to the presence of an arm relative to the helicopter center of gravity will turn it about.

The effectiveness of rudder control depends actually only on the forward flight speed and does not depend on the flight regime. In flight regimes where reversal of the yaw control of the main rotors is absent, the control moments from rotors and control surfaces are summed up, as a result of which the effectiveness of yaw control is augmented. When there is reversal of yaw control of the main rotors, the control moment from the rudder is superimposed with the opposite-signed moment from the rotors. This results in reducing the overall effectiveness of yaw control. Changes in overall yaw moment versus flight speed are illustrated in Figs. 3 and 4, from which it is clear that the overall yaw moment in autorotation is much less than in horizontal flight.

In spite of the fact that beginning at a certain autorotation velocity the reversal of the yaw control of rotors commences, the overall yaw control moment rises with increase in flight speed. At low velocities where steady autorotation is forbidden, but which can occur during the damping of velocity prior to landing, a reduction in yaw controllability by control surfaces is compensated by the pilot by increasing the collective pitch of the main rotors. When necessary, he can assist the course rotation of the craft also by sideway shifting of the cyclic pitch control stick. The motion of the control stick in this case induces a banking toward the side of its deflection, which produces the yaw control moment. The yaw moment with sideways deflection of the control stick is clearly evident in autorotation.

The presence of a rudder coupled with cyclic pitch on coaxial helicopters permits satisfactory yaw controllability in the autorotation regime. However, landing during autorotation with side wind must be avoided since the pilot may not have "enough" pedal room for yaw control. If there is no chance of coming in for a landing against the wind, the insufficient yaw moments must be induced by the deflection of the control stick sideway or by an increase in the autorotation speed.