SIMULATION OF UNCONTROLLABLE (“SPONTANEOUS”) ROTATION ON A HELICOPTER FLIGHT SIMULATOR

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Abstract

This paper presents the simulation predictions of the helicopter uncontrollable ("spontaneous") rotation obtained on the VPS-5 helicopter flight simulator. A special feature of the research was the use of the coefficients which take into account the tail rotor (TR) operation under uncontrollable rotation in the flight simulator mathematical model. During the simulation, the operator – pilot forced the helicopter into rotation about the vertical axis to the predetermined value of the rotation velocity (100 deg/sec, 120 deg/sec). After reaching the preset value of the rotation velocity, the operator-pilot recovered the helicopter from uncontrollable rotation by sharply kicking the right pedal to the hard stop. For these two regimes the yaw control power was shown and the comparison of the yaw control power with the minimum flying quality requirements was performed. The results of this study show that to prevent this helicopter from falling into uncontrolled rotation, it is necessary either to ensure the helicopter rotation rate limiting to the value at which the condition of generating the specified control power is met when fully kicking the right pedal or to increase the control power at a higher helicopter rotation rate.

1. INTRODUCTION

This paper presents the simulation predictions of the helicopter uncontrollable ("spontaneous") rotation obtained on the VPS-5 helicopter flight simulator. The VPS-5 is a helicopter flight simulator with a fixed cockpit and a spherical screen (Figure 1, 2).

The VPS-5 consists of a single pilot cockpit, a multi-channel out-of-the-window visual simulation with digital image generation, a computer assembly, an equipment interface, an electrical power supply system.

A special feature of the research was the use of the coefficients which take into account the tail rotor (TR) operation under uncontrollable rotation in the flight simulator mathematical model.

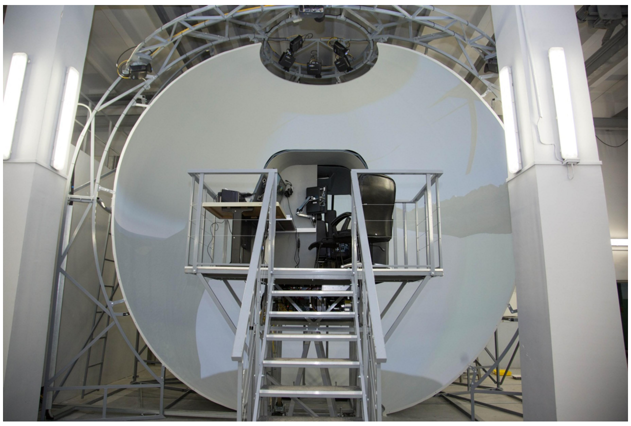

Figure 1

Figure 2

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The first coefficient $K^1_{p2} = f(V_x, V_z)$ takes into account a specific aspect of TR operation at low flight speeds with starboard sideslip (yaw instability of a single-rotor helicopter). The TR thrust is known [1] to change significantly due to the aerodynamic interaction of the main rotor wake with the tail rotor wake at low flight speeds. Figure 3 shows a change in the increment of the tail rotor trim pitch $\Delta\phi_{TR} = \phi_{TR} - \phi_{TRhover}$ (where ϕ_{TR} is a tail rotor trim pitch, $\phi_{TRhover}$ is a tail rotor trim pitch under hovering), as a function of the values of the sideslip velocities V_z for the four values of longitudinal velocities V_x obtained during the flight tests.

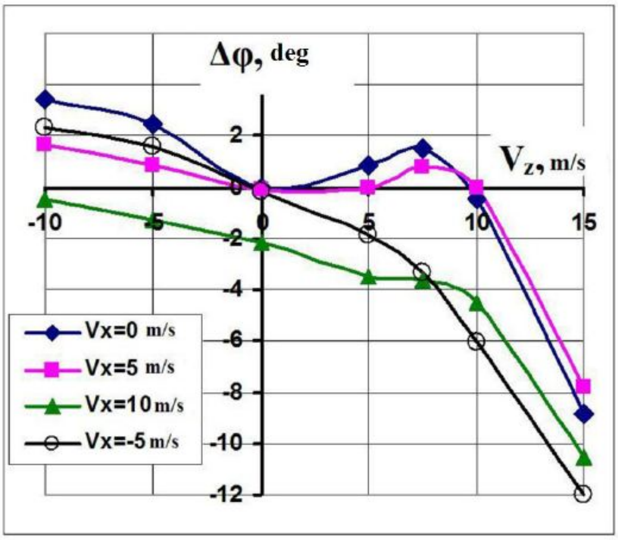

Figure 3

The dependencies obtained in the flight tests indicate a significant increase in the TR trim pitch at the airspeed range of $-5\text{m/s}<V_x<10\text{m/s}$ and $3\text{m/s}<V_z<12\text{m/s}$ and occurrence of the static instability of the yaw motion in this mode. Out of the specified airspeed range, but in the range of $-10\text{m/s}<V_z<15\text{m/s}$, the position of a trim tail rotor pitch has no peculiarities: an increase in the wind speed on the right requires a decrease in a tail rotor pitch, but an increase in the wind speed on the left - an increase in a tail rotor pitch.

The second coefficient $K^2_{p2} = f(\omega_y)$ takes into account the influence of helicopter rotation about the vertical axis on the TR thrust. Coefficient K^2_{p2} is calculated in a more complex mathematical model [2][3]. For example, the calculated value of the nondimensionalized TR thrust coefficient C_T/σ as a function of the rotation speed of a helicopter ω_y with different tail rotor pitches is shown in Figure 4. The calculation was carried out for a medium-lift helicopter.

It is seen that at the high tail rotor pitch there is a significant decrease in the tail rotor thrust. With the increase in the angular velocity of the helicopter rotation, the blade sections periodically fall into stall, reducing the total tail rotor thrust [2][4][5]. In Figure 4, the lower dotted curve corresponds to the trimmed hover mode at the altitude of $H \approx 50m$, and the upper curve corresponds to the same mode with addition of the normalized minimum required yaw control power ε_y [6].

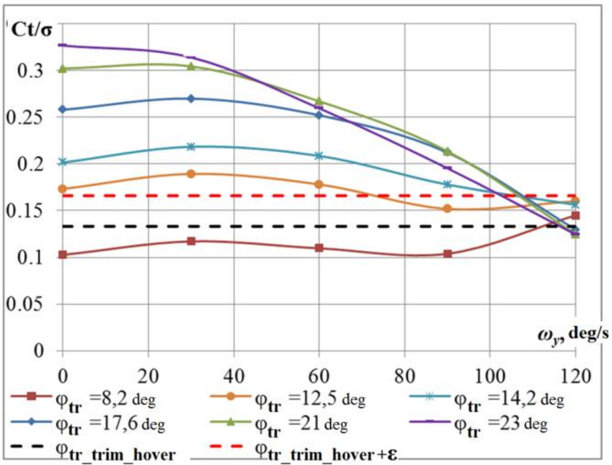

Figure 4

2. EXPERIMENTAL PROCEDURE

The experimental procedure for the helicopter flight simulator was as follows:

– the engineer, from the flight simulator engineer workplace, set the helicopter hover trim mode without ground effect at the specified pressure altitude;

– when the programmed helicopter trimming was completed, the flight simulator operator-pilot using a special indicator on the left LCD-monitor set the control sticks in trim position, activated the autopilot and restarted the simulation program after the pause command, then the “flight” mode started;

– the engineer communicated the value ω_y, which the helicopter should be set on and the uncontrolled rotation recovery should start from, to the operator-pilot;

– the operator-pilot turned on recording of the mode and then, smoothly changing the position of the control pedals, forced the helicopter into rotation about the vertical axis to the predetermined value of the rotation velocity ω_y;

– the current ω_y was monitored by the operator-pilot using a special indicator on the front instrument panel;

– the operator-pilot trimmed the hover mode using the low velocity indicator, the climb indicator and the altimeter;

– after reaching the preset ω_y, the operator-pilot recovered the helicopter from uncontrollable rotation by sharply kicking the right pedal to the hard stop, i.e. simulating the most unfavorable pilot's actions in terms of not-recovery from uncontrollable rotation.

The helicopter recovery from uncontrollable rotation was performed while maintaining a constant flight altitude, thus simulating the origin of uncontrollable rotation without altitude margin. All results were obtained for a medium helicopter in ISA at the hovering ceiling altitude $H \approx 3600m$.

3. RESULTS

Figures 5, 6 show entry of the helicopter into rotation at the angular velocity $\omega_y = 100\ deg/sec$ with subsequent kicking the right pedal to stop the rotation. At the top of Figure 5, the vertical velocity V_y, the main rotor collective pitch ϕ_{MR} and the tail rotor pitch ϕ_{TR} as functions of time are shown. At the bottom of Figure 5, the helicopter rotation speed ω_y as a function of time is presented. Figure 6 shows changes in the tail rotor thrust. It is seen that as the rotation speed of the helicopter ω_y increases, the operator-pilot tries to compensate for the decrease in the altitude, holding the magnitude of the vertical velocity V_y near zero position. After achieving the angular velocity $\omega_y = 100\ deg/sec$ and kicking the right pedal, the helicopter stops rotating. In this case, the helicopter does not enter uncontrollable rotation mode.

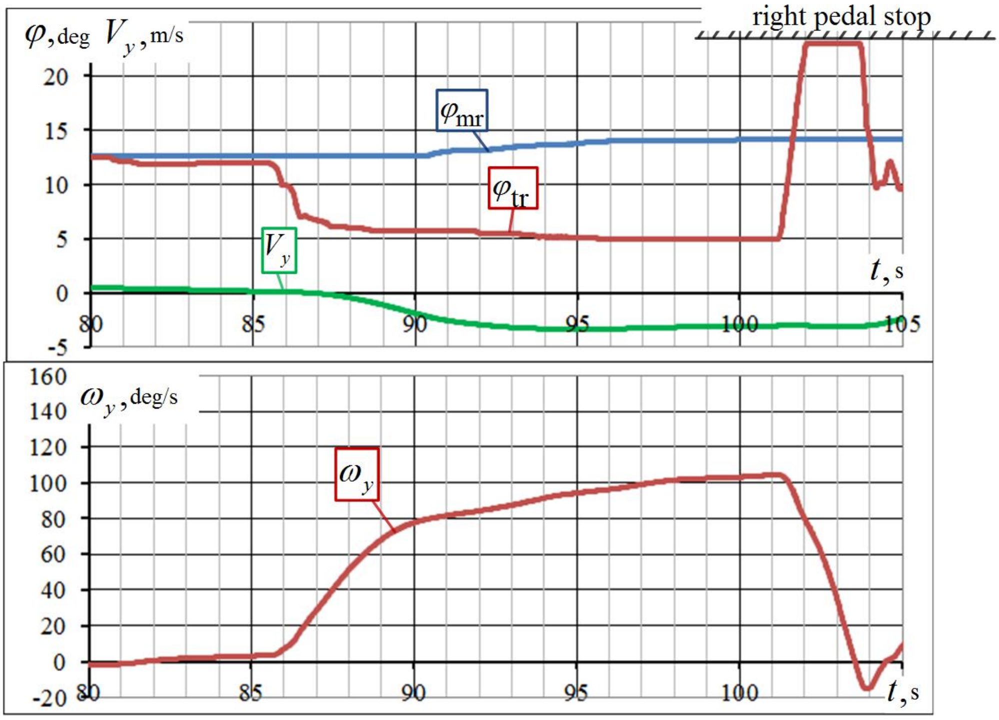

Figure 5

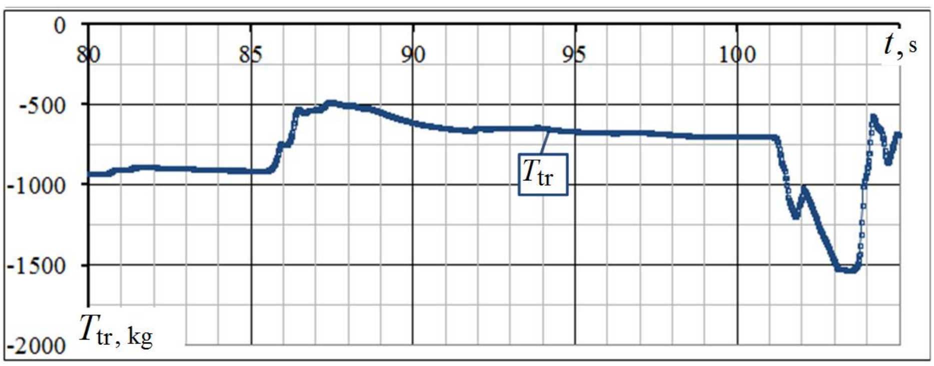

Figure 6

Let us consider the helicopter entry into rotation at the angular velocity $\omega_y = 120\ deg/sec$, the results are shown in Figures 7, 8. It is seen that as the rotation speed of the helicopter ω_y increases, the operator-pilot tries to compensate for the decrease in the altitude, holding the magnitude of the vertical velocity V_y near zero position as in the case of the first experiment. After achieving the angular velocity $\omega_y = 120\ deg/sec$ and kicking the right pedal, the helicopter rotation does not stop. In this case, the helicopter enters uncontrollable rotation mode.

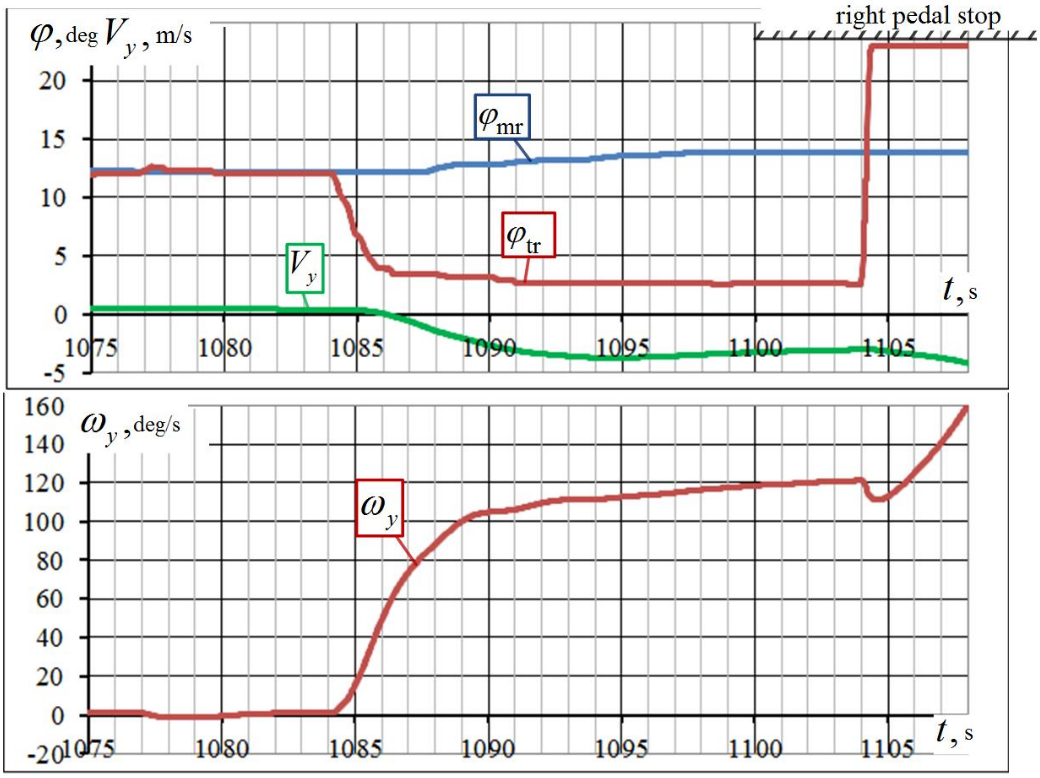

Figure 7

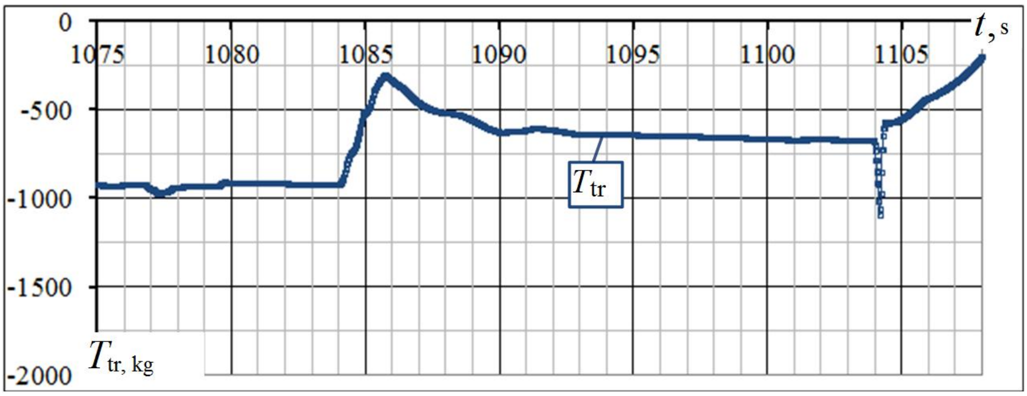

Figure 8

Based on this experiment, Table 1 shows the yaw control power ε_y. The power ε_y was calculated as follows: according to the diagram of TR thrust versus time (Figures 6, 8), the TR balancing thrust was taken in the steady-state rotation mode (for Figure 6 - $\omega_y = 100\ deg/sec$), then the increment of TR thrust ΔT was calculated relative to this thrust when kicking the right pedal to the maximum value. Then, the yaw control power was calculated using the formula $\varepsilon_y = \Delta T \cdot L_{TR}/J_y$ (ΔT stands for the increment of the tail rotor thrust relative to that for the steady rotation; J_y is the moment of inertia of the helicopter; L_{TR} is the distance from the centre of mass to the centre of the tail rotor hub).

Parameter	Value	
Rotation with ω_y, deg/s	100	120
Yaw control power, ε_y, 1/s^2	0.93	0.34..−0.12
Control result	**Recovery**	**No recovery**

Table 1

The yaw control power exceeds the minimum requirements of $\varepsilon_y \geq 0.3$ [6] at $\omega_y = 100\ deg/sec$. When $\omega_y = 120\ deg/sec$, the TR thrust first begins to increase, but then, with a further increase in the TR pitch, the thrust begins to decrease significantly, which leads to a change in control power from $0.34\ 1/s^2$ to negative values of $-0.12\ 1/s^2$.

4. CONCLUSION

The results of this study show that to prevent this helicopter from falling into uncontrolled rotation, it is necessary either to ensure the helicopter rotation rate limiting to the value at which the condition of generating the specified control power is met when fully kicking the right pedal or to increase the control power at a higher helicopter rotation rate.

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