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THRUST PULSATION OF COAXIAL MAIN ROTOR, CAUSED BY THE BLADES RELATIVE POSITION

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The influence of reciprocal position of the upper rotor blades in respect to the lower rotor blades is characteristic for coaxial main rotor. It is established that the initial azimuth of the blade, for example, of the upper rotor's which does not coincide with the initial azimuth of the lower rotor blades, affects the level of vibrations caused by the rotors thrust pulsations, the level of noise, generated mainly by coaxial rotor. This paper presents numerical studies which assess the effect of the initial azimuth of the upper rotor blades ("phasing") on the helicopter coaxial rotor thrust force pulsation. The research was carried out applying the calculation method based on the nonlinear vortex theory in a non-stationary formulation. The results of the helicopter coaxial rotor with different initial azimuths of the upper rotor blade relatively to the azimuth of the lower rotor blade flow around numerical simulation are presented. The influence of the blades "phasing" on the rotor thrust coefficient change and thrust force pulsation magnitude is shown. The flow of a six-bladed coaxial main rotor (two rotors with 3 blades) was simulated in the oblique flow mode at speeds of 51.25 m/s and 71.75 m/s at the rotor angles of attack– 5^0 and – 12^0, respectively. The change in the coefficient of the main rotor thrust per revolution at different values of "phasing" was studied. The coaxial rotor thrust coefficient is determined by summing the lower and upper rotors thrust coefficients respectively. Thus, at some "phasing" the thrust coefficient of the lower and upper rotors increase intensifies the thrust pulsations, and at others, the peaks of the upper and lower rotors pulsations are displaced and the total coaxial rotor thrust coefficient changes per one revolution with smaller amplitude. It is established what "phasing" produce the maximum values of thrust pulsation, and at which-a minimum of thrust pulsation.

Key words: coaxial rotor, thrust pulsation, blades relative position.

INTRODUCTION

The area where coaxial helicopters are applied is determined by their characteristic features – small overall dimension, high thrust-to-weight ratio and maneuverability, as well as aerodynamic symmetry (fig. 1). These features have provided them with a convenient base on small-sized take-off and landing sites of ships which are designed for various purposes. Features of coaxial helicopters are associated with the main rotors reactive moment compensating new method implementation compared to single-rotor helicopters. The coaxial helicopter propellers reactive moments are mutually balanced right on their axis of rotation. Due to the coaxial helicopter aerodynamic symmetry, there are almost no connections between longitudinal and lateral movement, independence of control channels and simplicity of piloting are provided [1].

At the same time, the helicopter with a coaxial design is made a demand to eliminate the upper and lower rotor blades collision during flight operation, reduce vibrations caused by the propeller thrust pulsations, and reduce noise generated mainly by the coaxial main rotor. It was determined that the blade initial azimuth of the upper propeller, for example, which does not coincide with the initial azimuth of the lower propeller blade, affects the above-mentioned features of the coaxial helicopter.

The upper rotor blades initial azimuth on the helicopter coaxial rotor thrust pulsation effect evaluation by means of computational methods seems to be rational. Currently, there are many methods for numerical study of helicopter main rotor aerodynamic characteristics. Calculation methods based on the non-stationary setting of nonlinear vortex theory both on the basis of a thin carrier surface [2 – 4] and on the basis of a carrier line (thread) [5] are distinguished among them. The first method allows you to determine the non – stationary aerodynamic characteristics of the main rotor with arbitrary shaped blades as planned, and the second – with the use of stationary results of helicopter profiles blowouts adjusted for non-stationarity.

Fig. 1. A coaxial helicopter Ка-226Т

A more detailed description of the main rotor blowout process is given by grid methods, both with and without taking into account viscosity. However, their application to main rotor aerodynamic characteristics determination is associated with a number of difficulties. Firstly, methods of this type require large computational resources, secondly, the calculation flapping movement of the blades and cyclic control for the forward flight mode (oblique flow mode) is associated with the solution of a number of special problems on calculated grids deformation. The main rotor operation on axial flow modes (hovering modes) [6 – 8] was mainly modeled applying grid methods.

The oblique flow mode of the helicopter main rotor is characterized by the flapping movement of the blades, swinging in the rotation plane, the blades elastic deformation and cyclic change in the angle of installation for one revolution of the propeller. The record of these features is demonstrated in [9]. However, this approach, which requires very large computational resources, is not appropriate for parametric exploratory research. Paper [10] demonstrating the example of hard main rotor modeling shows the application areas of different methods in various software packages. It is shown that the method based on the vortex theory demonstrates good results of the main rotor traction characteristics, especially, for calculating the main rotor vibration loads caused by thrust pulsation [11].

Therefore, this paper produces numerical studies on assessing the effect of the upper propeller blades initial azimuth on the helicopter coaxial main rotor thrust pulsation. The research was carried out using the calculation method based on the nonlinear vortex theory in a non-stationary setting.

ABOUT THE METHOD OF CALCULATION

This paper produces a numerical study on the basis of a nonlinear blade propeller theory in a non-stationary setting based on a thin bearing surface [2, 3]. According to this theory propeller blades are replaced by extremely thin base surfaces in the form of *Si* as planned coinciding with the shape of the blades themselves and curved according to the law of curvature of their median surfaces. An ideal incompressible medium is considered. The flow outside the propeller blades and their traces is considered to be vortex-free $\Delta\Phi=0$.

The following boundary conditions are met (fig. 2):

1. non-flow condition on bearing surfaces

$$(\nabla\Phi - \bar{W}^{*})\vec{n} = 0 \; (x, y, z) \in S_i ;$$

2. when passing through the surface of the vortex trace σ_i, the conditions of pressure continuity and the normal velocity component are observed

$$p_{-} = p_{+} \; (\nabla\Phi\vec{n})_{-} = (\nabla\Phi\vec{n})_{+} \; (x,y,z) \in \sigma_i ;$$

3. the Chaplygin-Zhukovsky hypothesis on the speed finiteness is fulfilled on the trailing edges of the bearing surfaces *Li,* which the vortex surfaces flow down from

$$(\nabla\Phi\vec{n})_{-} = (\nabla\Phi\vec{n})_{+} \; (\nabla\Phi\vec{n})_{-} = (\nabla\Phi\vec{n})_{+} \; (x,y,z) \in L_i ;$$

4. at an infinite distance from the propeller, as well as its trace, the disturbances fade away

$$\lim_{R\to\infty} \nabla\Phi = 0 \text{, where } \quad R = \sqrt{x^2 + y^2 + z^2} .$$

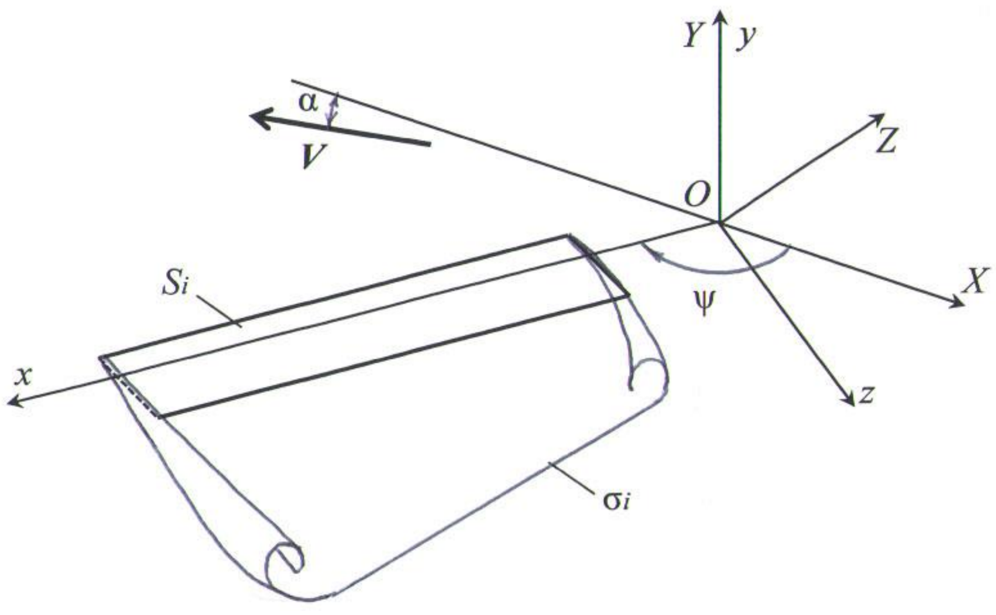


Fig. 2. The boundary conditions at the blades and their vortex wakes

The numerical method for main rotor problem solution in a nonlinear non-stationary setting according to the method of discrete vortices consists in discretization over space and time. Confluent vortex layers, which model the base surfaces of the propeller blades and their vortex wakes, are replaced by the systems of discrete vortex frames, and the time-continuous process of changing boundary conditions and flow parameters is replaced by a stepped process. The values of kinematic parameters remain unchanged within a single time step. At each time period, starting with the first one, after having solved the system of equations for determining the circulations, there are some tensions of all vortex frames of blade systems and their trace. Distributed and total propeller characteristics are determined by summing the aerodynamic load on the panels. The wake form is drawn up as a result of calculation (fig. 3). The numerical method for the helicopter main rotor aerodynamic characteristics determination, which is under consideration, has been carefully approbated and the approbation justified the reliability of the results obtained [2 – 5].

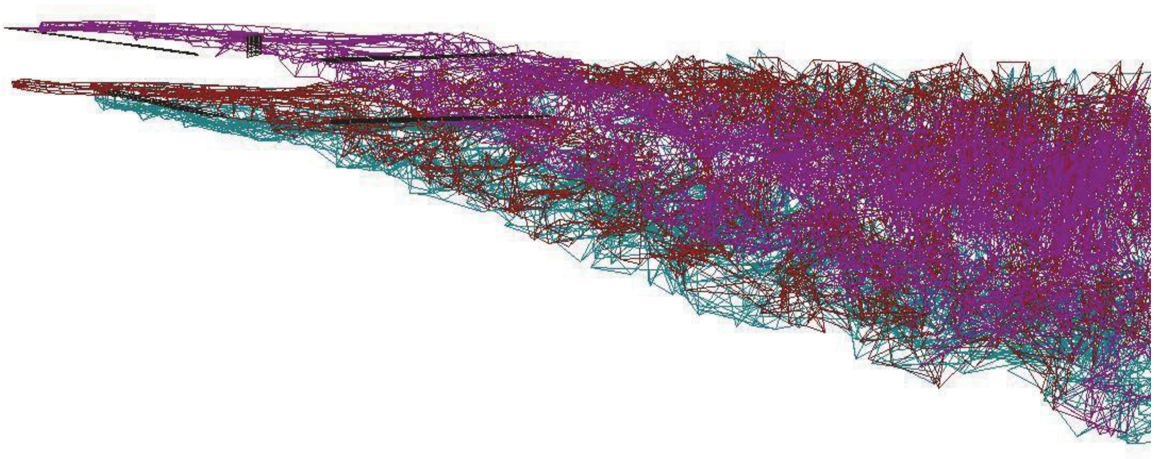


Fig. 3. The wake behind a coaxial rotor vortex structure

COMPUTATIONAL RESEARCH RESULTS

We studied the flow of a six-blade coaxial main rotor (two propellers with 3 blades) in the oblique flow mode at speeds of V_1=51.25 m/s (the angle of attack of the propeller $\alpha_н$ = -5^0) and V_2 =71.75 m/s ($\alpha_н$ = -12^0). Propeller geometric and kinematic parameters are shown in Table 1.

Table 1

Coaxial rotor geometric and kinematic parameters

The main rotor radius	R = 4.2 m	The angle of blades setting	$\varphi_0 = 10^0$
Finned section radius	r_0 = 0.42R	Velocity of rotation	ωR = 205 m/sec
Blade chord	B = 0.206 m	Blade mass center	lц.м.= 0.52R
Distance between the propellers	h = 0.1D	Horizontal hinge removal	lг.ш.= 0.02R (0.084 m)
Blade mass	m =10.2 kg	Swing compensator factor	k = 0.726

Modeling of the main rotor non-stationary airflow starts with the moment when the lower propeller blade takes the initial position with the azimuth of ψ = 0. The second upper propeller blade can take the position with the azimuth other than zero, for example, with a shift by a certain angle $\Delta\psi$, which is conditionally called "phase" or "phasing" (fig. 4). The first lower propeller rotates counter-clockwise when viewed from above, and the second upper propeller – clockwise. Depending on the phase of $\Delta\psi$ while rotating the upper and lower propellers blades intersect at different time moments.

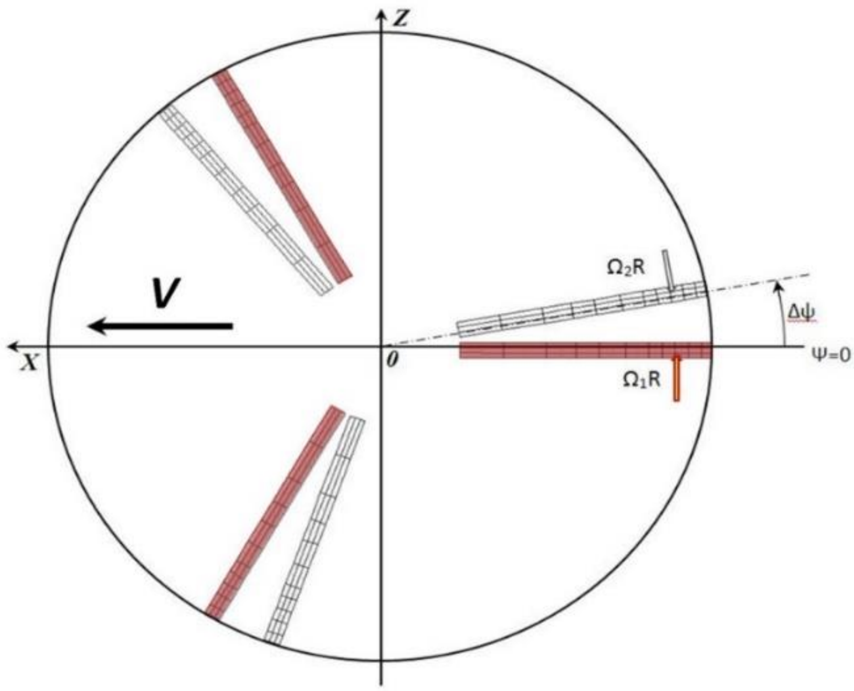


Fig. 4. The main rotor blades initial azimuth

It is determined that the phase of Δψ affects the nature of the coaxial main rotor upper and lower blades convergence character as well as thrust pulsations and noise produced by the propellers load. This paper estimates the upper propeller Δψ phase effect on the helicopter coaxial main rotor thrust pulsation. We studied the change of the main rotor thrust coefficient *C*т per one revolution at Δψ = 0, 20, 30, 40, 60, 80, 100, 120 degrees.

The main rotor thrust coefficient *C*т is determined by summing the lower *C*т*l* and upper *C*т*u* propellers thrust coefficients respectively. For example, at the speed of V1=51.25 m/s with Δψ = 0 the upper and lower propeller coefficient increase reinforces thrust pulsation (fig. 5, a), but at Δψ = -600 the upper and lower propeller pulsation peaks are shifted and the total thrust coefficient *C*т of coaxial main rotor changes per one rotation with a smaller amplitude (fig. 5, b).

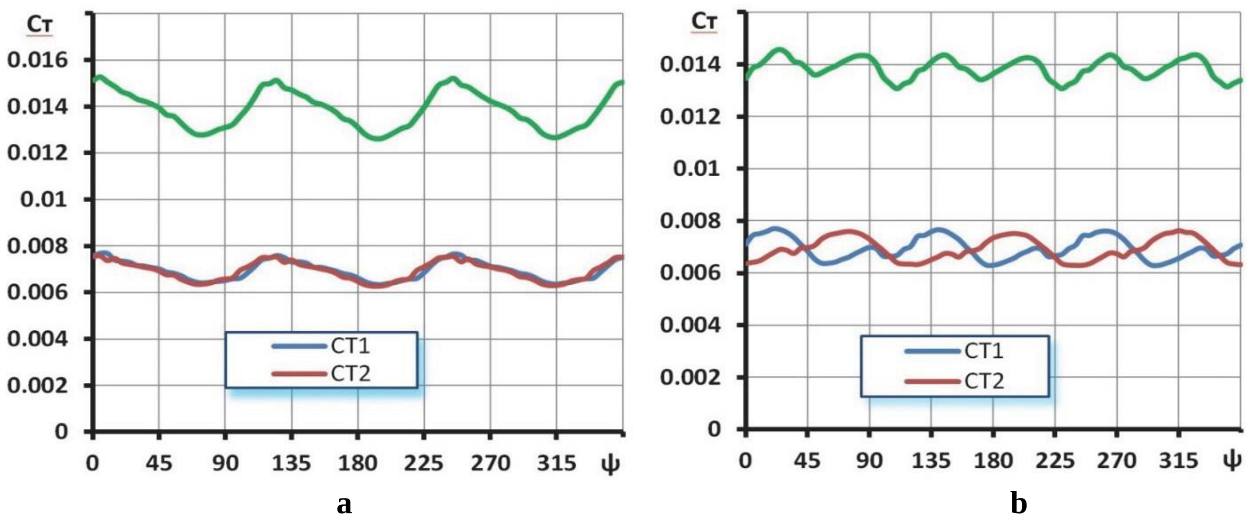
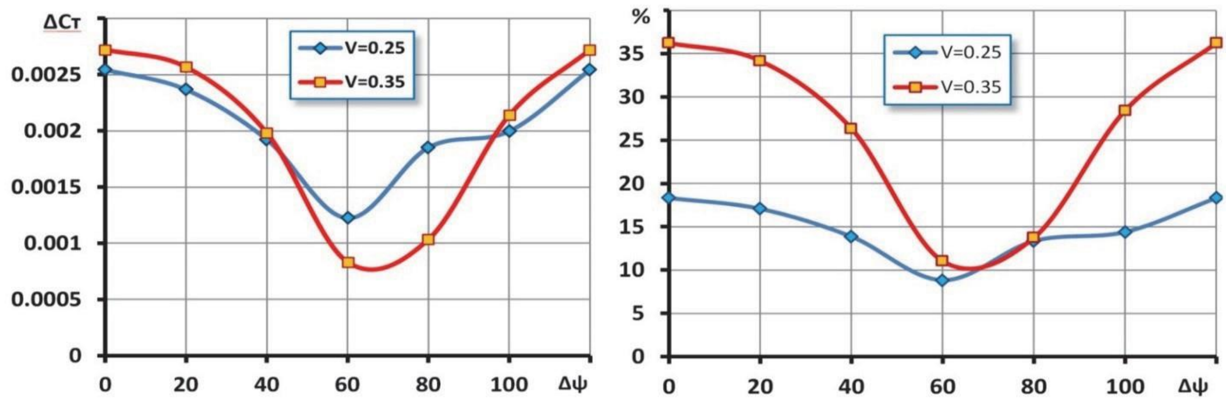


Fig. 5. Change in the propellers thrust coefficient per one revolution at Δψ = 0 (a) and Δψ = 60^0 (b)

Figure 6a demonstrates coaxial main rotor thrust coefficient pulsations calculation results $\Delta C_T = C_{TMAX} - C_{TMIN}$ for two flow velocity values V_1=51.25 m/sec ($V_1/\omega R$=0.25) and V_2=71.75 m/sec ($V_2/\omega R$=0.35), while Figure 6b presents thrust pulsations as percentage of the average C_T value for the same speed values.



a b

Fig. 6. The phase effect on thrust coefficient change C_T (a) and coaxial main rotor thrust pulsation amplitude in percentage of the average value of C_T (b)

The analysis of the results obtained makes it possible to assess the effect of the upper propeller blades initial azimuth Δψ on the helicopter coaxial main rotor thrust pulsation. In particular, when the values of the upper rotor initial azimuth are about zero, we can see the occurrence of the thrust pulsation maximum values, which, for example, when the flow velocity equals to V_2=71.75 m/s exceeds the average value of C_T, by 35% but minimum thrust pulsation – at $\Delta\psi \approx 60^0$.

CONCLUSION

When adjusting the layout of the coaxial main rotor, it is necessary to take into account the blades relative position at their initial azimuths. It is important both from the position of excluding the coaxial main rotor blades inter collision in oblique flow modes, and reducing vibrations caused by propeller thrust pulsation. Thus, the reduction of helicopter vibrations can be achieved, along with the blade high harmonics individual control application [4], nd taking into account the blades of coaxial main rotor relative position.

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ПУЛЬСАЦИИ ТЯГИ СООСНОГО НЕСУЩЕГО ВИНТА, ОБУСЛОВЛЕННЫЕ ВЗАИМНЫМ РАСПОЛОЖЕНИЕМ ЛОПАСТЕЙ

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Для соосного несущего винта характерно влияние взаимного расположения лопастей верхнего винта относительно нижнего. Установлено, что начальный азимут лопасти, например, верхнего винта, не совпадающий с начальным азимутом лопасти нижнего винта, влияет на уровень вибраций, обусловленных пульсациями тяги винтов, на уровень шума, генерируемого, главным образом, соосным несущим винтом. В данной работе выполнены численные исследования по оценке влияния начального азимута лопастей верхнего винта («фазировки») на пульсации силы тяги соосного несущего винта вертолета. Исследования проводились с помощью метода расчета, основанного на нелинейной вихревой теории в нестационарной постановке. Приводятся результаты численного моделирования обтекания соосного несущего винта вертолета с разными начальными азимутами лопасти верхнего винта относительно азимута лопасти нижнего винта. Показано влияние «фазировки» лопастей на изменение коэффициента силы тяги винта и величину пульсации силы тяги. Моделировалось обтекание шестилопастного соосного несущего винта (два винта по 3 лопасти) на режиме косого обтекания на скоростях 51.25 м/с и 71.75 м/с при углах атаки винта – 5^0 и – 12^0 соответственно. Изучалось изменение коэффициента тяги несущего винта за один оборот при различных значениях «фазировки». Коэффициент тяги соосного несущего винта определяется суммированием коэффициентов тяги соответственно нижнего и верхнего винтов. Таким образом, при некоторых «фазировках» приращения коэффициента тяги нижнего и верхнего винтов усиливают пульсации тяги, а при других – пики пульсаций верхнего и нижнего винтов смещены и суммарный коэффициент тяги соосного несущего винта изменяется за один оборот с меньшей амплитудой. Установлено, при каких «фазировках» имеют место максимальные величины пульсации тяги, и при которых – минимум пульсации тяги.

Ключевые слова: соосный несущий винт, пульсация тяги, взаимное расположение лопастей.

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