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# NUMERICAL SIMULATION OF AERODYNAMIC CHARACTERISTICS OF HELICOPTER ROTOR BLADES

***Abstract**: The results of helicopter flight simulation under conditions of the development of the rotor speed up to 300 rpm were presented in the article. Vector schemes of load distribution and air flow velocity along the length of the rotor blades were demonstrated. The results of numerical simulation of the deflection of the rotor blades were presented during takeoff and flight of the helicopter. The aerodynamic characteristics and the material stress of the rotor blades for one revolution around its axis were analyzed.*
***Key words**: helicopter, rotor blade, lift force, degree.*
***Language**: English*

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**Introduction**

A helicopter is an aircraft in which the lifting and driving forces at all stages of the flight are created by one or more rotors [1].

The complexity of the helicopter control lies in the constant elimination of emerging forces and moments on the elements of the aircraft both on the ground and during maneuvers [2-3]. Compared to an airplane, the helicopter is not fully dynamically balanced for different weather conditions.

The main rotor of the helicopter is a drive structure that includes a swashplate and several fixed blades [4-7]. The blades, due to the change in the angle of attack, create a lift force of the necessary magnitude to takeoff of the helicopter. The swashplate provides adjustment of the forces arising due to the action of ascending or descending air flows when performing the helicopter maneuvers. The swashplate includes a number of parts that work synchronously: a non-rotating outer ring, a turning inner ring, a ball joint, controls and linkages to the rotor blade.

The topic of the helicopter aerodynamics has been researched and optimized in a number of articles [8-10]. The use of special computer programs and well-known laws of aerodynamics made it possible to perform a full-fledged calculation of the simulated helicopter flight in the atmosphere. However, there are very few studies on the simultaneous influence of several parameters on the stability of the helicopter flight. Therefore, the purpose of the study was a visual representation of the calculated values of some aerodynamic characteristics of the rotor blades and their effect on the helicopter flight.

**Materials and methods**

The process of rotation of the helicopter rotor at a speed of 300 rpm was simulated. For this purpose, a model of the swashplate with blades mounted on it was created. The helicopter model was not created, which allowed to reduce the calculation time. The models of the parts included in the swashplate were given the properties of structural steel: density – 7850 kg/m$^3$; heat capacity at constant pressure – 475 J/(kg×K); thermal conductivity – 44.5 W/(m×K); electrical conductivity – 4.032×10$^6$ S/m; coefficient of thermal expansion – 12.3×10$^{-6}$ 1/K; Young's modulus – 200×10$^9$ Pa; Poisson's ratio – 0.33; Lamé parameter (λ) – 1.5×10$^{11}$ N/m$^2$; Lamé parameter (μ) – 7.5×10$^{10}$ Pa. The calculation method was as follows:

1. Functions are written to determine the variables under study.
2. A module is selected to perform numerical simulation of the process.
3. The boundary conditions for solving the problem are set: the equation of state, connections, loads, etc.
4. The quality of modeling results is set by generating a mesh on the model with a certain size of the finite element.
5. The type of study with the time limits of the process calculation is selected.

The results of numerical modeling were presented in the form of schematic and graphical figures. The frequency analysis of eigenfrequencies of the rotor blades of the helicopter was carried out at 0.17124 and 11.739 Hz. The aerodynamic characteristics of the rotor blades of the helicopter were represented by the calculated maximum and minimum values of the studied parameters in the form of graphs constructed in the Excel program. The calculated values were obtained by modeling one revolution of the main rotor.

**Results and discussion**

Figure 1 (*A-C*) shows the load distribution on the rotor blade at 0, 180 and 360 degrees of rotation, respectively. The rotor blade is considered in longitudinal section. Vectors determine the direction and magnitude of the load along the length of the rotor blade. From the vector diagrams presented, it can be seen that during the rotation of the main rotor, the load on the blade increases proportionally and reaches the highest value at the tip. At the same time, at the beginning of turning the rotor, the action of the load down from the blade is noted, and at 180 degrees of rotation or more, the load acts up from the blade. When the rotor is half-turned, the load acts on 2/3 of the blade length, in other cases, the load acts on the entire length of the blade. This is due to the appearance of a lift force that tends to bend the blade upwards. Figure 1 (*D*) shows the distribution of air flow velocity on the rotor blades of the helicopter when viewed from the top view. There is a proportional increase in speed on the rotor blades of the helicopter with the highest value at the tip. The direction of rotation of the rotor blades is clockwise.

Eigenfrequencies of the rotor blade of the helicopter were determined at low and high frequencies (Fig. 2). This made it possible to identify deflections of the rotor blade under various operating conditions of the helicopter without taking into account forced vibrations arising from the action of external forces. Since elastic rotor blades were used for the calculation, at a high frequency, eigenfrequencies deflect the rotor blade upwards by 10-11 degrees from the initial position. Thus, bending oscillations occur, which increase with increasing rotation speed of the helicopter rotor.

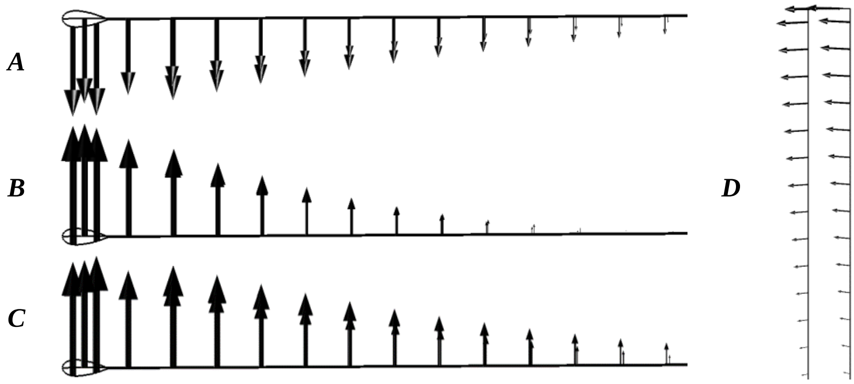


**Figure 1. Load distribution (in the form of vectors) on the length of the rotor blade of the helicopter (*A*-*C*) and the distribution of air flow velocity on the rotor blade of the helicopter (*D*).**


**Figure 2. The deflection of the rotor blade of the helicopter from the initial position at eigenfrequencies of 0.17124 Hz (*A*) and 11.739 Hz (*B*).**

It should be noted that the calculated values of the angle of attack, lift force, relative velocity and von Mises stress were determined for three turning rotor blades of the helicopter (Fig. 3). In one revolution of the main rotor, the angles of attack of the blades vary in the range from 2 to 17 degrees. The angle of attack is positive. At the same time, the angle of rotation of the blades in the range of 0-90 degrees leads to an increase and maintenance of the same angle of attack for all three rotor blades of the helicopter. This effect provides an increase in the lift force. Further rotation of the blades leads to a change in the value of the angle of attack according to an increasing and decreasing function. However, due to the same change in the angle of attack of the blades at the maximum and minimum values, the main rotor aerodynamics process will be stable due to the functions of the swashplate, which allows balancing the excess loads acting on the blades.

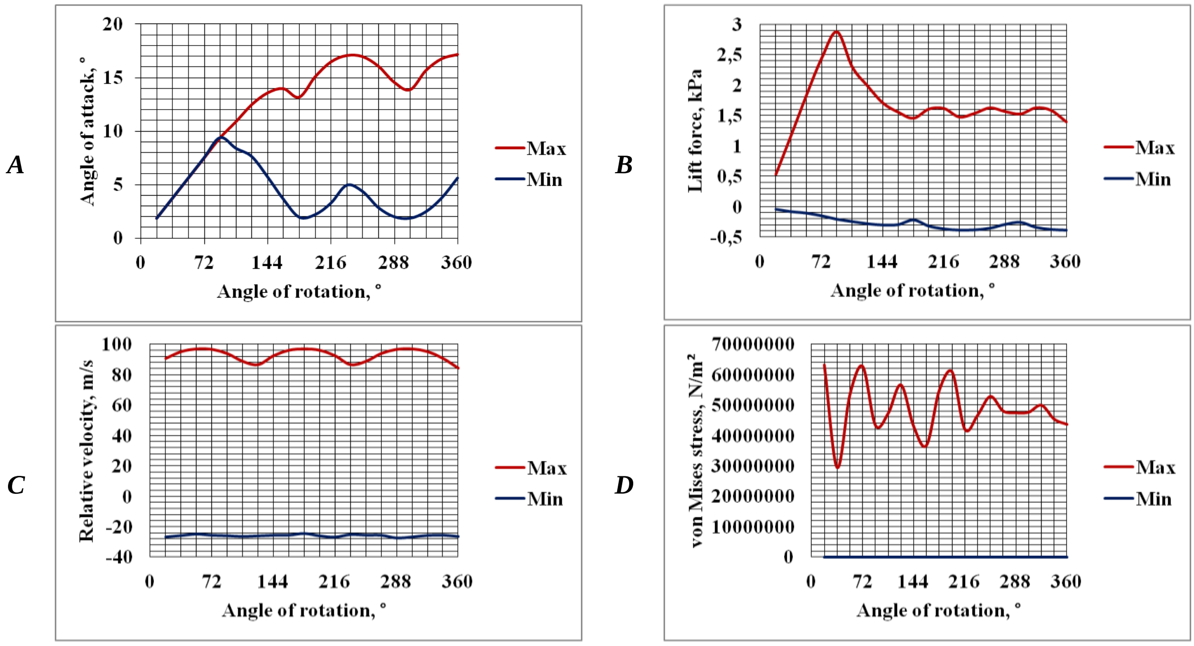


**Figure 3. The dependences of the angle of attack (*A*), lift force (*B*), relative velocity (*C*) and von Mises stress (*D*) on the angle of rotation of the helicopter rotor.**

The lift force increases with a simultaneous equal increase in the values of the angles of attack of the rotor blades of the helicopter. The maximum value of the lift force was determined when the main rotor rotates 90 degrees around its axis. Further, the value of the lift force is halved due to changes in the angles of attack in the range of 15 degrees. The lift force with a negative value leads to a downward deflection of the rotor blades. For a full revolution of the helicopter rotor, this phenomenon was observed on the blades, but the deflection is minimal.

The relative velocity is calculated as a function that includes variable and constant parameters, such as the angular velocity of the rotor, the distance from the center and the forward speed of the helicopter. The relative velocity varies by a certain amplitude in a small numerical range. In this case, negative values of the relative velocity were determined for the swashplate.

Stresses in the material are caused by vibrations of the helicopter rotor blades. It is noted that an abrupt change in the von Mises stress to the maximum values occurs when the azimuthal position of the rotor blade of the helicopter is from 0 to 270 degrees. In the last 90 degrees of rotation of the main rotor, the blades are almost equally deformed.

**Conclusion**

Based on the analysis of the results of numerical modeling of the aerodynamic characteristics of the rotor blades of the helicopter, the following conclusions can be drawn:

1. It is determined that in order to prevent the occurrence of significant vibrations and variable loads, the rotor blades, depending on the maneuver performed by the helicopter, can deviate up or down by the certain angle. When the main rotor performs a half-turn around its axis, the blades are subjected to a slightly lower load than when the rotor is fully turned.

2. Checking the eigenfrequencies of the blades at a higher rotational speed of the helicopter rotor showed the absence of significant cyclic loads leading to resonance.

3. The interrelation of some aerodynamic characteristics of the blades for one revolution of the helicopter rotor was presented. It is noted that the greatest lift force is provided by the blades having at the same time the angle of attack of 9.5 degrees. However, the maximum lift force creates the maximum load on the rotor blades of the helicopter, which proves the dependence of von Mises stress of the blade material on the angle of rotation of the helicopter rotor.

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