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NUMERICAL CFD ANALYSIS OF AN AERODYNAMIC HEAD COVER OF A ROTORCRAFT MOTOR

Autogyros can become an alternative for the use of rotorcrafts in various fields of life, including agroforestry. They have better economic performance than helicopters, owing to, among other things, the presence of a bearing rotor. Most autogyros also have other advantages in terms of no need for the compliance with stringent regulatory regulations – with respect to new constructions, lower combustion, noise and emissions of toxic elements. The cover of the bearing rotor head is an important element of rotorcrafts, which demonstrates that aerodynamics plays an important role in aerodynamic designs. Therefore, in this article, air flow model testing is carried out for two types of the bearing rotor blades of an autogyro with and without a cover using the ANSYS Fluent program. An aerodynamic drag analysis was also performed.

Keywords: *CFD numerical analysis, autogyro, aerodynamic cover, rotor head*

1. Introduction

Aviation is one of the most advanced technical disciplines used in many fields of life, including agriculture. A large number of experts and resources allocated to the technological development of this field of knowledge enable the establishment and development of the new and unconventional ideas and the popularization of their applications.

The intensive development of helicopters has been slowing down due to the limitations of the operation of rotors at the highest revolutions [1]. The development of the so-called "gyrocopters", which combine the construction of autogyros, helicopters and planes, is an alternative direction for rotorcrafts. They have very desirable options for vertical takeoff, landing and drift.

Autogyros, economically better than helicopters, can also be a good choice. The advantage is that their bearing rotors are driven by the incoming air, causing the effect of autorotation, which means that, unlike helicopters, they are not propelled by the engine on the fly. Every autogyro has a motor, of course, but it serves to propel the bearing blade exactly as in the case of motorcycles [2], [3], [4].

Autogyros most commonly make use of piston engines and it is the use of piston engines that makes them cheaper to operate. The strength of the machines is also the possibility to execute a short take-off and landing, which eliminates the need for a hardened and long runway. Autogyros contrast with most of the mentioned rotorcrafts, also with reference to the legalization of new constructions. Unlike the previously mentioned machines, most autogyros are not subject to rigorous regulations.

The four-person PAV (Personal Air Vehicle) by Carter Copter is an example of such means of travel [5], [6]. The highly innovative PAV consumes three times less fuel than the standard helicopters. What is more, the model is characterized by low emission of toxic elements and low noise during operation. It seems that the presented strengths provide a favorable future for this type of a flying craft.

The cover of the bearing rotor is an important element affecting the performance of autogyros - its aerodynamics plays an important role in the design of aircrafts. The shape of the mast significantly influences traveling at high speeds. Therefore, they are rarely used in the low-speed rotorcrafts. The structures of the cover of bearing rotor heads, depending on the design, are full- or half-covers. Therefore, it seems that the analysis of this element can affect the direction of production and thus improve the performance which, in turn, can also contribute to the increase of the popularity of autogyros in Poland and in the world [1], [7], [8].

2. Study aim

The aim of the study was to perform the air flow model testing for two types of autogyro bearing rotor heads using the ANSYS Fluent program and to perform an aerodynamic drag analysis.

3. Assumptions and scope of simulation tests

The scope of the model study included four airflow simulations for two types of the bearing rotor heads of a rotorcraft - with and without a cover. The simulations were made for two air velocities of 140 and 200 km/h. For each velocity, an individual angle of the bearing rotor adjustment was selected. Different parameters of the rake angle of the rotor are due to the fact that for different velocities different bearing rotor rake angles are used. The rake angles of the bearing rotor heads for each velocity are determined in Figure 1 [9]. It was decided to refer to a graph showing the parameters of the classic autogyro rotary engine. The rotor rake

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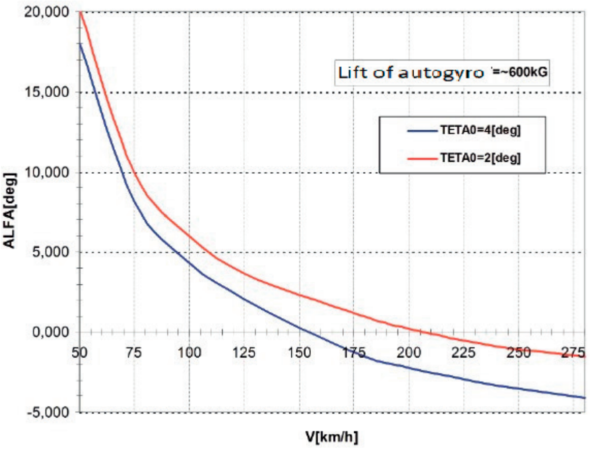
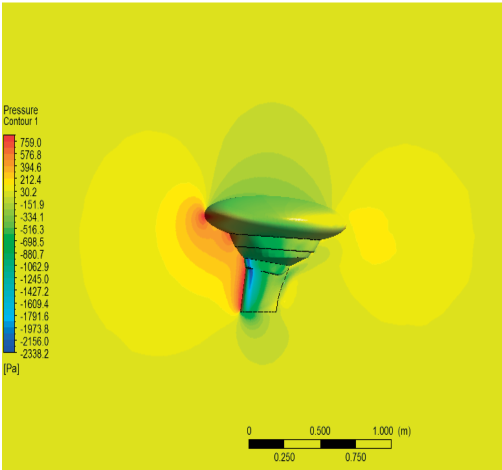


Figure 1 *Graph of the rake angles of the bearing rotor head as a function of the autogyro velocity for two blade position angles [9]*

Table 1 *Bearing rotor rake angles for different flight speeds*

Speed	Rake angle
140	3°
200	0°



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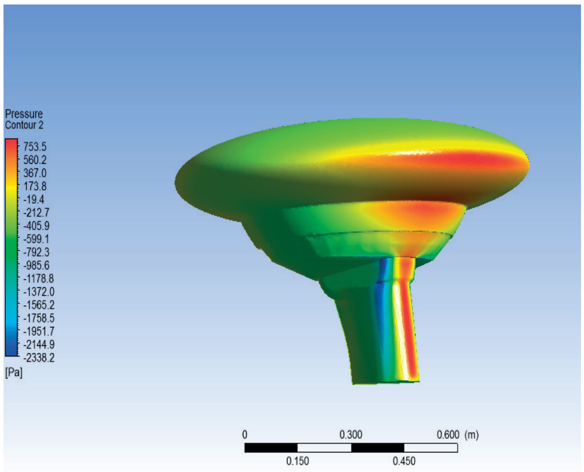

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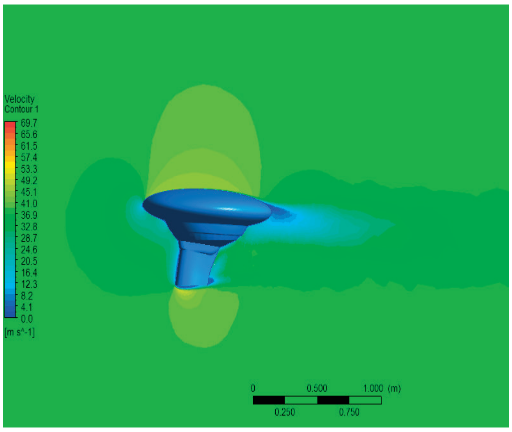

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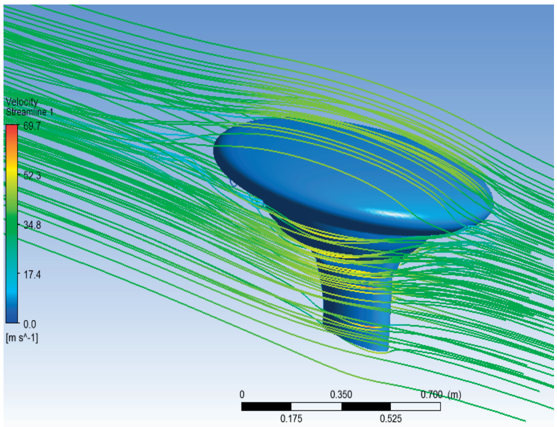

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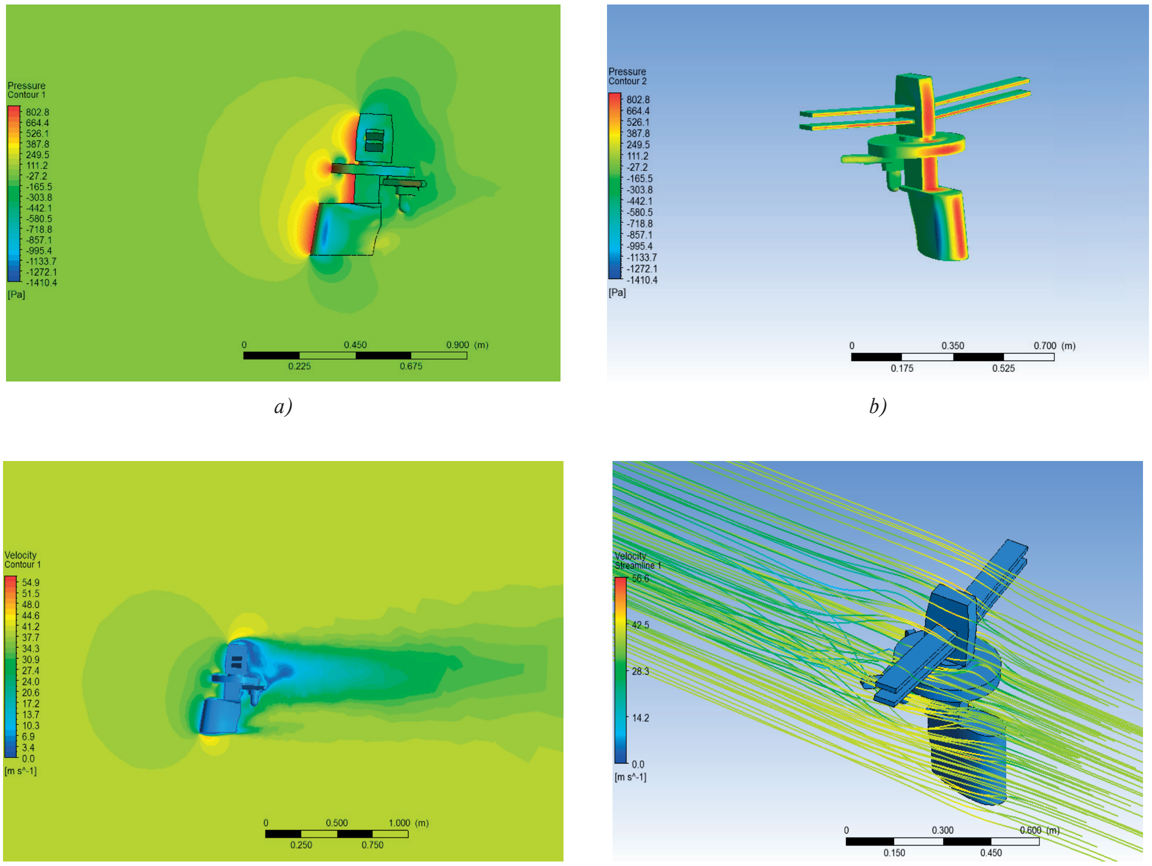
Figure 2 *Calculation results for model I. a) pressure gradient for the head rake angle 3°; b) Pressure gradient for the head rake angle 3°; c) velocity gradient for the head rake angle 3°; d) current lines for the head rake angle 3°*

angles were adjusted to the blade position at an angle of 2 degrees. The selected rake angles are shown in Table 1.

For model testing, the following assumptions were made:

– flow through the geometry is incompressible; this is due to the Mach number not exceeding 0.3,
– the phenomenon under consideration is stationary,
– turbulent airflow was assumed,
– aluminum was assumed as the material for the autogyro from the Ansys Fluent material base,
– it was assumed that the calculation solver that is used to solve the fluid mechanics equations is pressure-based,
– the two-tone turbulence model k-ω SST was assumed,
– the second-order interpolation for energy equations, momentum, kinetic energy of turbulence, turbulence dissipation energy was assumed.



a) b)

c) d)

Figure 3 *Calculation results for model II: a) pressure gradient for the head rake angle 3°; b) pressure gradient for the head rake angle 3°; c) velocity gradient for the head rake angle 3°; d) current lines for the head rake angle 3°*

In development of the assumptions and the scope of testing, literature [9] and [10] have been applied, as well as the general state of knowledge on airflow simulation and its effects on the body.

4. Analysis of the test results

The analysis of the results is based on the illustration calculations concerning the pressure gradients, velocities and currents running through a computational domain. The current lines represent the flow behavior. The speed of the stream is shown in colors. Pressure gradients are shown in individual areas - in the symmetry plane of the heads and on their surface. The values of the characteristic aerodynamic parameters were also analyzed.

The results of the calculations are presented in order from the minimum velocity tested (140 km/h) to the maximum velocity tested (200 km/h), starting with the head with an aerodynamic cover.

4.1 Model I

Figure 2 shows the calculation results for the head with an aerodynamic cover. The results show a model with an air velocity of 140 km/h and a rake angle of the bearing rotor head of 3°.

After the preliminary analysis of results obtained for Model I, it can be seen that the face surface of the head is characterized by the largest areas of high pressure, while the side walls of the mast exhibit areas of vacuum.

4.2 Model II

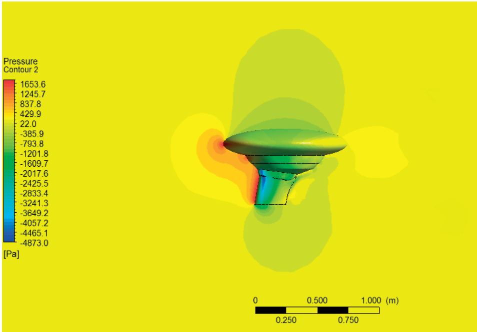
Figure 3 shows the results of the calculation for the standard head. The results show a model with an air velocity of 140 km / h and a rake angle of the bearing rotor head of 3°.

Based on the results of model II, it can be seen that there are high pressure areas on the flat face areas. The values are higher than in the model with an aerodynamic cover.

4.3 Model III

Figure 4 shows the calculation results for the head with an aerodynamic cover. The results show a model with an air velocity of 200 km/h and a rake angle of the bearing rotor head 0°.

When analyzing the results of calculations for the Model III, it can be seen that the highest pressure is present on the face surfaces of the head aerodynamic cover. The value of the pressure there is twice as great as in the case of the first model. The values of the pressures on the side walls of the mast showed the same characteristics.



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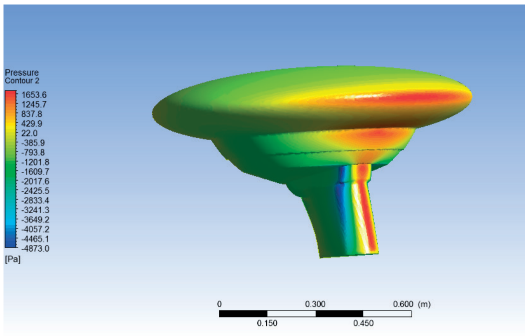

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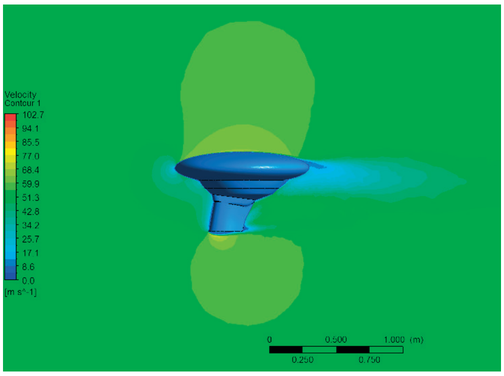

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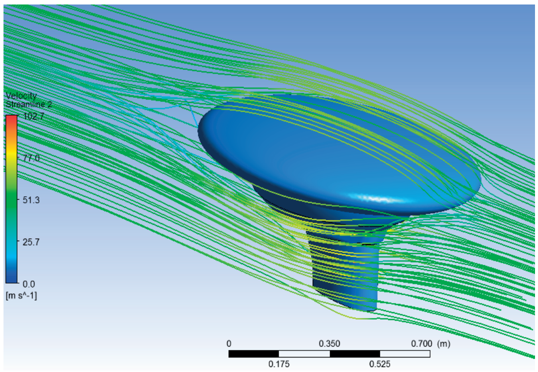

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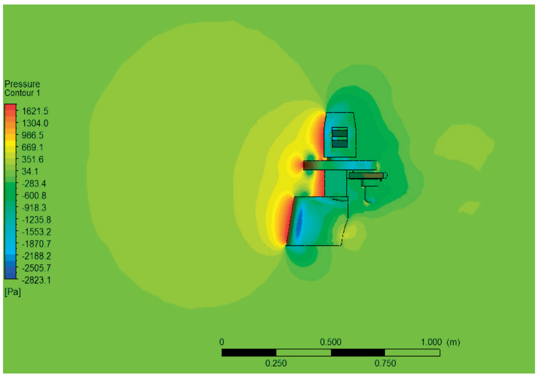
Figure 4 *Calculation results for model III: a) pressure gradient for the head rake angle 0°; b) pressure gradient for the head rake angle 0°; c) velocity gradient for the head rake angle 0°; d) current lines for the head rake angle 0°*



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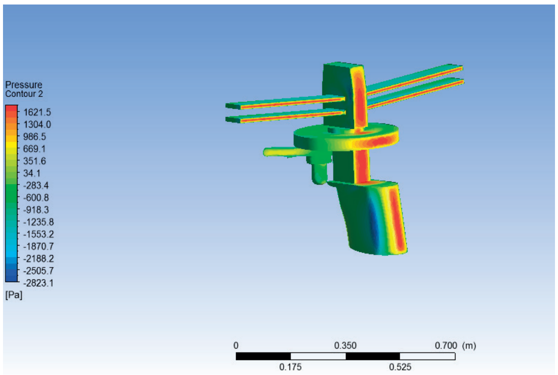

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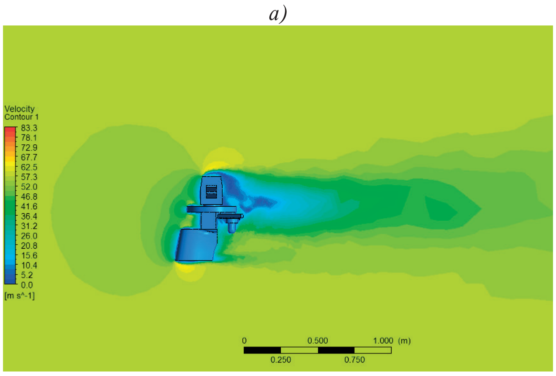

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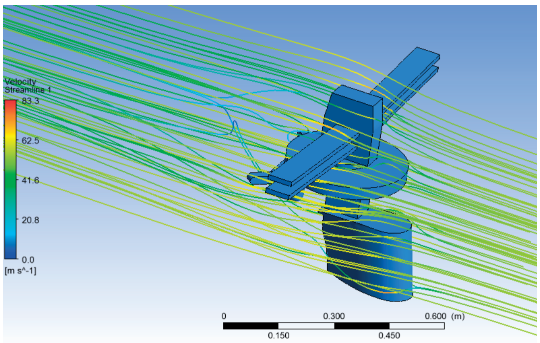

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Figure 5 *Calculation results for model IV: a) pressure gradient for the head rake angle 0° b) pressure gradient for the head rake angle 0° c) velocity gradient for the head rake angle 0° d) current lines for the head rake angle 0°*

Table 2 Values of the aerodynamic parameters of the analyzed heads

rake angle of the head	F_x	F_y	F_z	C_x	C_y	C_z
without a cover / 3°	71.435	-1.786	-3.584	0.743	-0.019	-0.037
with a cover / 3°	36.468	-1.577	49.578	0.142	-0.006	0.193
without a cover / 0°	149.746	-0.807	-11.253	0.844	-0.005	-0.063
with a cover / 0°	75.280	4.790	45.479	0.145	0.009	0.087

F_x - aerodynamic resistance,
F_z - lifting force,
F_y - aerodynamic lateral force

C_x - Spring of aerodynamic resistance,
C_z - Youth supporting,
C_y - aerodynamic lateral force.

4.4 Model IV

Figure 5 shows the results of the calculation for the standard head. The results show a model with an airflow velocity of 200 km/h, while the rake angle of the bearing rotor is 0°.

The analyzed model IV has recorded the high pressure areas that occur on the front surfaces. The overpressure value of the last model is twice that of the second model, but has a value similar to the model analyzed for the same flight speed. After analyzing the results obtained for the two types of the bearing rotor heads and the two speeds of the autogyro, the highest pressure values were found on the front areas. It was also observed that the pressure gradient for flat surfaces is much larger than for the spherical areas of the aerodynamic cover. The above illustrations also show areas of vacuum on the mast side surfaces. Low pressure is present on the mast walls and is a result of the Bernoulli's law influence. Reducing the flow surface of the model results in an increase in air velocity that results in a vacuum in the areas. This phenomenon can also be seen in the area above the rotor head cover. Since the geometry of the aerodynamic cover is similar to the airplane profile, the distribution of pressure fields in the areas is similar. For the models analyzed, the value of aerodynamic forces was measured. The readings were used for calculations of the most important aerodynamic coefficients which are presented in Table 2.

The results show the beneficial effect of the aerodynamic cover. The highest coefficient of aerodynamic drag was recorded for the standard head at the rake angle of the bearing rotor head 0°. The bearing rotor head with an aerodynamic cover has more than four times the lower value of the aerodynamic drag coefficient. An additional advantage of the aerodynamic cover design is the positive value of the lift force coefficient. The value of the lift force coefficient for the bearing rotor head rake angle changed by 3° increased more than twice.

5. Summary

One of the most important goals in aircraft design is to achieve satisfactory aerodynamic performance. The strive for improving and increasing the quality can be achieved through changing the geometry of aircrafts.

The results obtained after four airflow simulations for two types of bearing rotor heads of a rotorcraft (with and without a cover) show that the heads with aerodynamic covers have more favorable aerodynamic properties. The aforementioned heads have a four times lower aerodynamic drag coefficient, which significantly affects the aircraft's flying performance.

The presented studies provide a good basis for conducting further simulations. In the next stages, it will be possible to perform a simulation using the whole autogyro model or a head with rotating blades. The simulation studies under discussion can be extended by both a vertical and diagonal flight of an aircraft.

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