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A COMPUTATIONAL STUDY ON IMPROVING THE PERFORMANCE OF A SMALL UNMANNED HELICOPTER BY MODIFYING ITS MAIN ROTOR

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Abstract

The research presented aimed to evaluate the possibility of modifying the main rotor of a small UAV helicopter so that the modified rotor could lift the helicopter heavier by 67% compared to the baseline. Within a frame of the presented study, a sensitivity analysis of changes in the rotor thrust and the power necessary to drive the rotor was carried out, depending on changes in several geometric parameters like number of blades, rotor radius, blade planform and geometric twist, base airfoil of the blade. To calculate the performance of various variants of the main rotor, the Virtual Blade Model (VBM) methodology was used, developed in the form of an original software package extending the computational capabilities of the ANSYS FLUENT program. The research focused on searching for a rotor configuration that would require minimal power to drive the rotor to achieve the required lift generated by the rotor. Results of the rotor-optimisation process were presented.

Keywords: UAV, rotorcraft, main rotor, design and optimisation

1. Research motivation, subject and goals

The research described in the paper was carried out as part of the project MUSE no. DOB-SZAFIR/01/B/038/04/2021 entitled "Multi-sensory platform for imaging and detecting threats occurring in areas with high dynamics of changes in environmental conditions". The aim of the project is to develop:

- a threat detection and imaging system equipped with a machine learning system to create prioritization of threats occurring in the monitored area or battlefield;
- a system of two flying platforms based on two types of carrier units: an aeroplane and a helicopter to present the system functionality in a marine environment.

The research work described in this paper concerns only one of the flying platforms - a small unmanned helicopter, the conceptual design of which is shown in Figure 1. To be more precise, the described works aimed to evaluate the possibility of modifying the main rotor of the helicopter shown in Figure 1 so that the modified rotor could lift the helicopter heavier by 67% compared to the baseline. The rotor baseline configuration was a two-blade teetering rotor with rectangular, untwisted blades with an aspect ratio of 15. Within a frame of the presented study, a sensitivity analysis of changes in the rotor thrust (T) and the power (P) necessary to drive the rotor was carried out, depending on changes in the following rotor design parameters:

- number of blades,
- rotor radius,
- blade chord,
- blade-tip planform,

- blade geometric twist,
- shape of the blade cross-section (blade airfoil)

The research focused on searching for a main-rotor configuration that would require minimal power, necessary to drive the rotor to achieve the required lift generated by the rotor.

Figure 1 The concept of a small unmanned helicopter is the subject of the research discussed in the paper.

2. Research methodology

To calculate the performance of various variants of the main rotor, the Virtual Blade Model (VBM) methodology was used, developed in the form of an original software package extending the computational capabilities of the ANSYS FLUENT program. The methodology is based on the coupling of the Blade Element Theory with the U/RANS (Unsteady/Reynolds Averaged Navier-Stokes) solver. The applied computational methodology [2], thanks to the simplifications used, allows you to quickly determine the aerodynamic characteristics of the main rotor while maintaining relatively high reliability of the results. The VBM method instead of true modelling of rotor blade geometry, utilizes aerodynamic characteristics of airfoils – blade cross-sections. These characteristics were calculated using a two-dimensional version of the ANSYS FLUENT code. When optimising the dimensions of rotor blades the original in-house method was developed. This method enables the determination optimal span of the rotor blade to minimise the power driving the main rotor in hover, for the assumed thrust generated by the rotor. In general, the method is based on the definition of Figure of Merit - a coefficient describing the aerodynamic efficiency of the rotor in hover.

3. Research results

During the research, the aerodynamic characteristics of several dozen rotor variants were analysed in two assumed helicopter flight conditions:

1. Hover at altitude 50 masl
2. Forward Flight at altitude 50 masl and flight speed V=140 km/h

Figure 2 shows the dependence of the power required to drive the main rotor generating the required thrust needed to keep the helicopter in the air, on the number of rotor blades. The presented graph clearly shows that the efficiency of the rotor decreases with the increase in the number of blades. Therefore, further studies on the optimization of the main rotor were carried out only for a two-blade teetering rotor, such as in the baseline version of the helicopter.

In the next step, the rotor radius was optimized to obtain its highest aerodynamic efficiency in hovering at the required thrust generated by the rotor. Based on the original, in-house optimization methodology, it was determined, that the optimal rotor radius should be 35% larger than the baseline rotor radius. However, due to design constraints, the final optimized main rotor of the helicopter has a radius that is 30% larger than the base rotor.

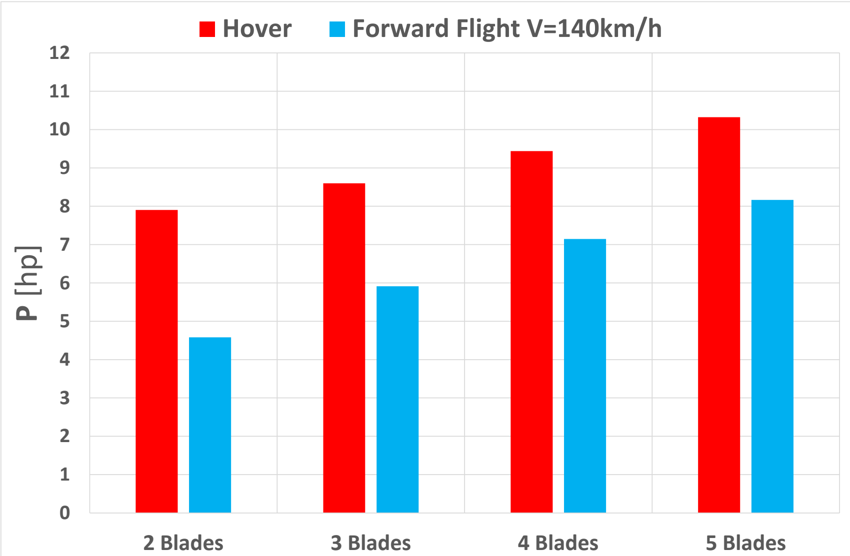

Figure 2. the dependence of the power required to drive the main rotor generating the required thrust needed to keep the helicopter in the air, on the number of rotor blades

Ultimately, as the most promising solution, a two-blade teetering rotor with rectangular, untwisted blades whose radius was increased by 30% compared to the baseline rotor blades was recommended to the helicopter designers. Figure 3 presents the dependence of the power (P) vs flight speed (V), determined computationally for the base variant of the rotor (BASELINE) and the finally selected variant (FINAL DESIGN). The aerodynamic characteristics of both rotors were calculated for the conditions of balanced helicopter flight, i.e. where the collective pitch angle of the rotor blades and the helicopter pitch angle were determined so that the vertical and horizontal components of the rotor thrust vector balanced the weight and drag force of the helicopter, respectively. As seen in Figure 3, compared to the baseline, the modified rotor characterises itself by a decrease of necessary power of up to 17% in the range of low-speed flight and hover. In the range of higher-speed flight (above 130 km/h), the differences in necessary power for both rotors disappear. Figure 4 compares the dependences of thrust (T) vs power (P) calculated in hover for two compared rotors, for two hovering altitudes of 50 and 6000 masl. As one can see, the modified rotor, in this case also has better aerodynamic and performance properties than the baseline rotor.

4. Conclusions

Based on an original design and optimization methodology, a main rotor was designed for a small, unmanned helicopter to allow for a significantly greater payload of the helicopter compared to its initial version. The finally optimised main rotor, compared to the initial version, characterises itself by a decrease of necessary power of up to 17% in the range of low-speed flight and hover. In the range of higher-speed flight (above 130 km/h), the differences in necessary power for both rotors disappear. The optimised main rotor has also significantly better performance in hover on extremely high altitudes of order of 6000 masl.

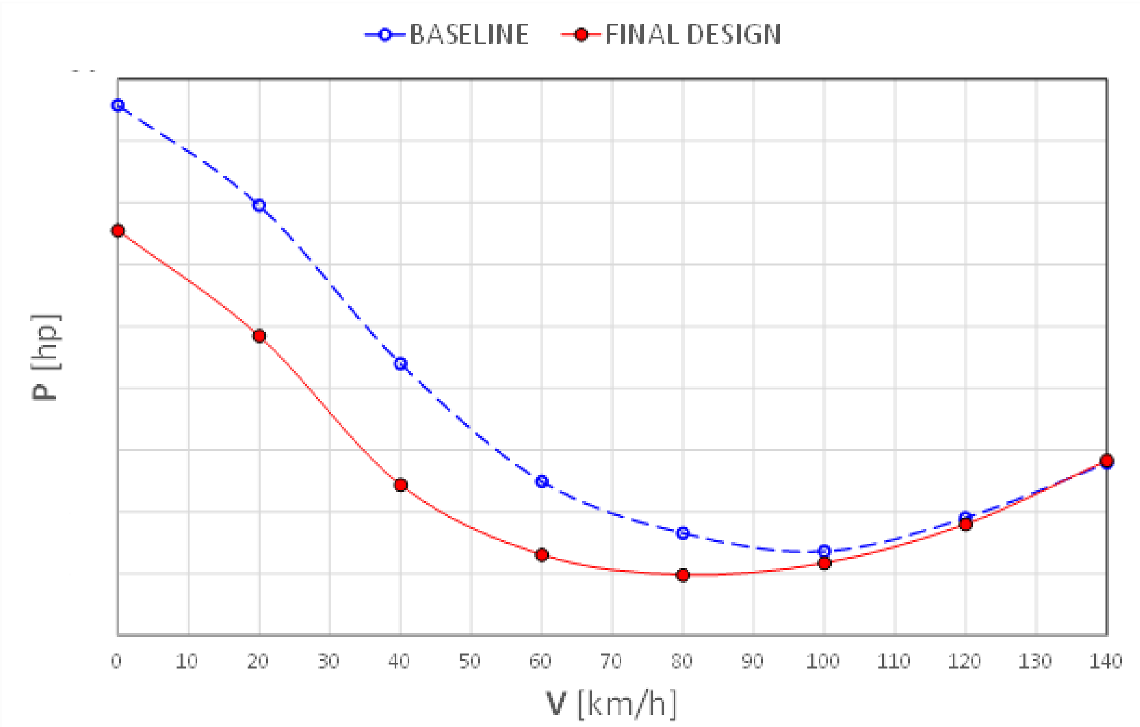

Figure 3 Comparison of the dependence of the power (P) vs flight speed (V), determined computationally for the base variant of the rotor (BASELINE) and the finally selected optimized variant (FINAL DESIGN), in a balanced flight of a helicopter.

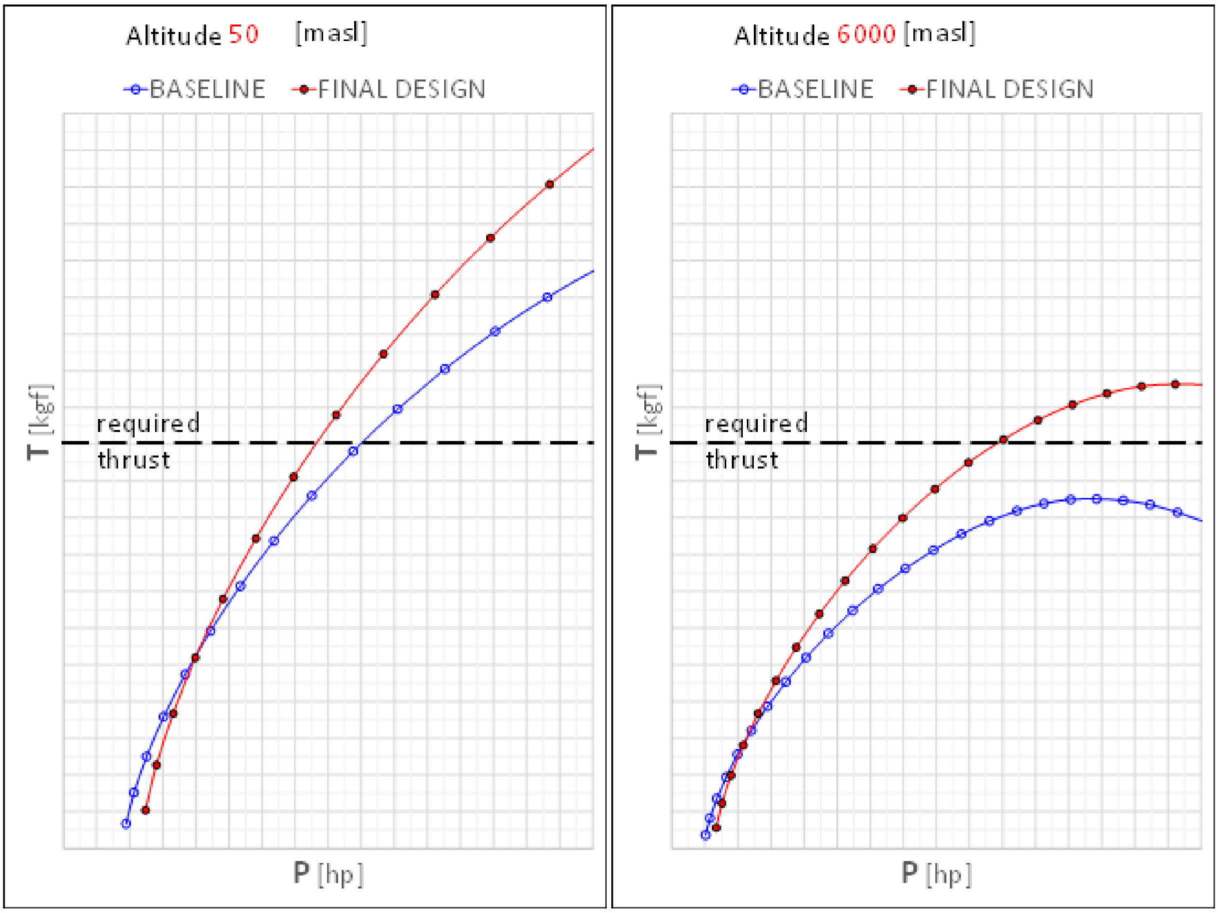

Figure 4. Dependences of thrust (T) vs power (P), calculated in hover for two compared rotors, for a hovering altitude of 50 masl (left) and 6000 masl (right).

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6. Copyright Statement

Acknowledgements

The research described in the paper was carried out as part of the project "MUSE" no. DOB-SZAFIR/01/B/038/04/2021 entitled "Multi-sensory platform for imaging and detecting threats occurring in areas with high dynamics of changes in environmental conditions".

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