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DESIGN OF THE PROPELLER FOR TILT-ROTOR UAV

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Abstract: Tilt-wing and tilt-rotor unmanned aerial vehicles (UAVs) represents promising direction for the future development. This paper presents the method for the preliminary design optimization of the propeller for such vehicle. It should be capable to generate high thrust in both forward flight and hover modes. This brings design challenges for the propeller aerodynamic design. All considered variants have same number of blades, engine power, airfoils and diameter. Thrust in forward cruise speed 30 m/s and in hover is computed and compared by the means of Pareto diagram. Choose of the optimal RPM is based on the computation results.

Keywords: propeller design, VTOL, tilt-wing, UAV

1 Introduction

Tilt-wing and tilt-rotor unmanned aerial vehicles (UAVs) represents promising direction for the future development. They represent the combination of the conventional aircraft with fixed wings and rotorcraft. They offer Capability of the vertical take off and landing connected with the possibility of efficient high speed cruise. This is very important in the situation when the area of interest is relatively far from the possible take-off and landing area. Use of quadrocopters is limited by their inefficiency in forward flight. Thus the development of this type of vertical take-off and landing (VTOL) UAVs looks to be very important for the future.

This paper is devoted to the preliminary optimization study of the propeller for tilt-wing VTOL UAV, which is currently under development at the Department of Aerospace Engineering, Czech Technical university in Prague.

2 Problem Description

Aerodynamic design of propeller is based on [1]. This represents modification of the methods developed by Larrabee ([2], based on [3]), Broz ([4]) and Goldstein ([5], usually uses tabulated values, e.g. [6]). The method combines advantages of Goldstein (i.e. accurate solution for inviscid case and any number of blades) and Broz (i.e. influence of viscosity for high number of blades) and describes the influence of viscosity on the propeller design for any design conditions. It is based on the variational formulation of the aerodynamic design of the optimal propeller.

Design conditions for the two-blade propeller are flight velocity in forward cruise 30 m/s, engine shaft power 500 W, propeller diameter 0.6 m, spinner diameter equal to 20% of the propeller diameter. Propeller was designed for cruise conditions. Model of the airfoil aerodynamic characteristics from [7] is used for the off-design performance estimation of the propeller. Propeller advance ratio $\lambda = V/(nD)$ was corrected by the means of the mean axial induced velocity v (see Figure 1). Induced velocities were computed by the means of Biot-Savart law. Vortex system consists of horseshoe vortices (see Figure 2). Propeller RPM are varied from 2,000 to 8,500 (upper limit corresponds to the tip Mach number 0.8). Propeller thrust in hover and forward cruise flight are computed for given engine power and RPM. The objective is to find optimal propeller in design point so that highest possible thrust is reached in both forward cruise and hover.

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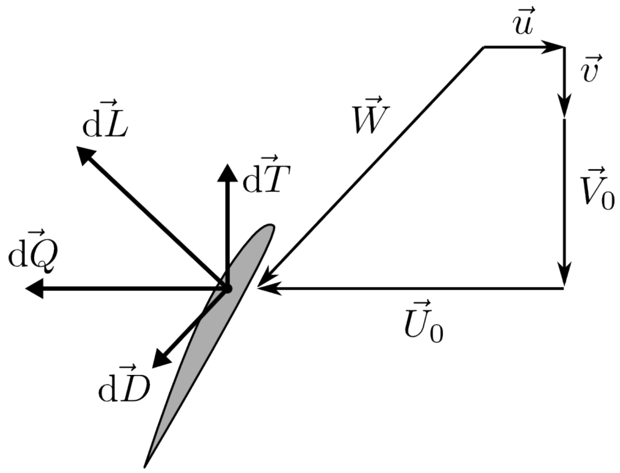

Figure 1: Velocities and forces on a propeller blade

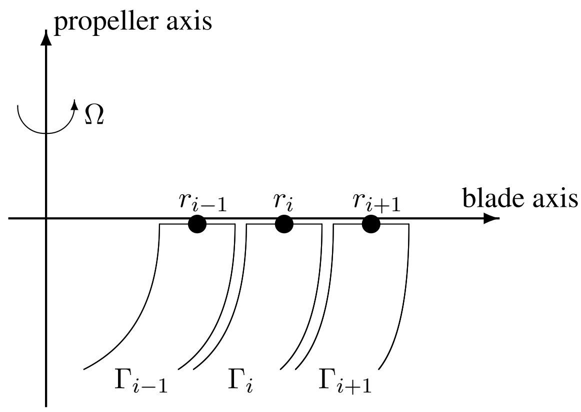

Figure 2: Vortex system on a propeller blade

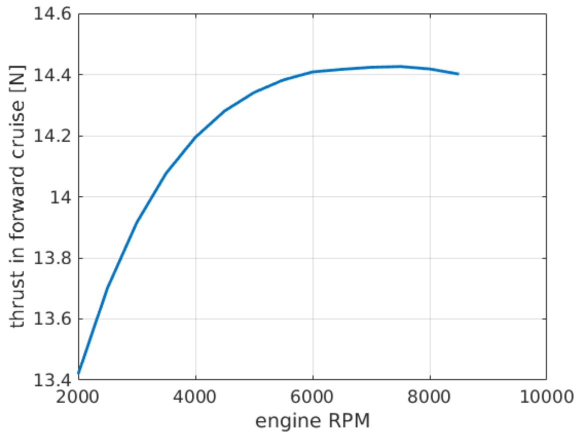

Figure 3: Thrust in the forward cruise on the design propeller RPM

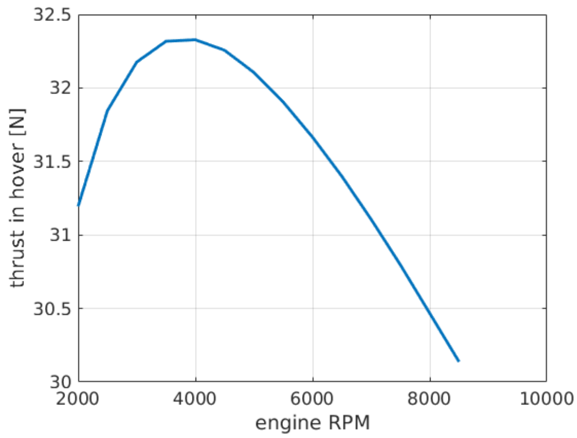

Figure 4: Thrust in hover on the design propeller RPM

3 Results

Dependence of propeller thrust in forward cruise flight on design propeller RPM is shown in Figure 3. Dependence of propeller thrust in hover on design propeller RPM is presented in Figure 4. From these figures alone it is quite difficult to choose the optimal solution of the problem. Thus, Pareto diagram (Figure 5) was used to find the best RPM for the propeller. The optimal RPM were chosen as 5,000. According to the Pareto diagram it represents good compromise between the thrust in hover and in forward cruise. It also has favorable Mach blade tip number approximately 0.47, which means low noise generation.

4 Conclusion

The method of the preliminary design optimization of the tilt-wing VTOL UAV is presented. Propeller should be capable to generate high thrust in both forward flight and hover modes. This brings design challenges for the propeller aerodynamic design. All considered variants have same number of blades, engine power, airfoils and diameter. Each case is designed for different engine RPM from 2,000 to 8,000. Thrust in forward cruise speed 30 m/s and in hover is computed and compared by the means of Pareto diagram. Optimal RPM was chosen as 5,000. This combines good compromise in thrust and

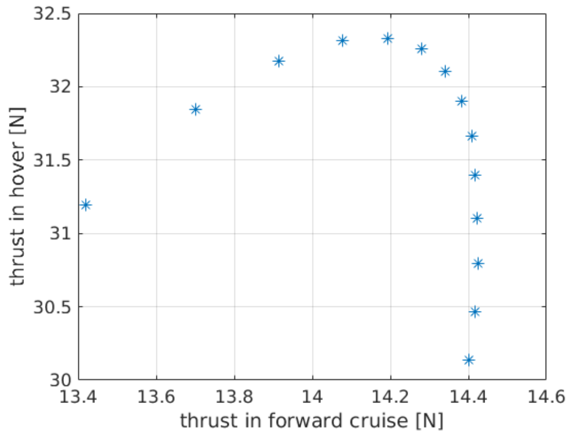

Figure 5: Pareto diagram

moderate Mach number at blade tip, i.e. low noise generation.

5 Acknowledgment

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