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Title

Study of geometry effects on aerodynamics and aeroacoustics of various scale rotors

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Abstract

The parametric analysis of propeller blades was performed, to examine the influence of blade geometry on aerodynamics and aeroacoustics in the multi-objective, global optimization context. Propellers of two scales were considered: 0.1m radius (Micro Air Vehicle class) and 1.5m radius (Urban Air Mobility class), to investigate similarities and differences arising from different rotor scales.

The generic parametric models were defined using spline-based distributions of chords and twists along the radius. Additionally, airfoil cambers were added to the model, extending it by radially-varying airfoil. The analysis involved typical operating conditions – hover for both MAV and UAM scales, and additional forward-flight scenario for UAM.

The aerodynamic model utilized in this work relies on blade-resolving, high-fidelity RANS, which allows to fully address the effects of complex flow features (especially in hover). Consequently, the shortcomings of low-fidelity blade element-based methods – typically used in propeller global optimization – were eliminated. The aeroacoustic model was split to tonal and broadband components. Non-permeable Ffowcs-Williams and Hawkings (FWH) was used to calculate tonal noise basing on the RANS solution, while semi-empirical model for airfoil self-noise was used to calculate the broadband noise. The local inflow inputs for broadband noise calculations – including effective angle of attack and turbulence – were extracted from RANS to increase the model fidelity. The modeling approach was validated against the experiment.

The sample of design points was defined using space-filling algorithm to generate surrogate models of selected functions of interest. Parameters' bounds were determined using low-fidelity code, to ensure desired propeller properties. Kriging surrogate models of: thrust, sound pressure level (SPL) and efficiency were created and used to perform global sensitivity analysis using Sobol' indices. The relative importance of geometric parameters and rotational speed was determined, along with the mutual interactions between parameters. Depending on the function of interest, the relative importance of parameters was different. Surrogate-based optima were determined, to explore the potential trade-offs between aerodynamic and aeroacoustic objectives.

This work provides a study of the propeller blade parametrization for the global aerodynamic and aeroacoustic optimization. High-fidelity aerodynamic model ensures high accuracy of obtained results in the whole design space. Physical explanation of data-driven conclusions were discussed, to provide insights and build intuition in propeller blade design. Consequently, conclusions drawn from this study can be used in defining an efficient optimization strategy for any propeller.