Aeroacoustics of Stacked UAV Rotors – Progress on Computational and Experimental Study

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Introduction

This presentation outlines the progress made in computational and experimental work on the aeroacoustics of stacked rotors, defined as coaxial and co-rotating. The work is carried out within the INTERNOISE project at the Institute of Aviation (ILOT), which is focused on the aeroacoustic aspects of rotor-rotor and rotor-airframe interactions, and follows the SILENT ROTOR project, where testing and optimisation methodologies for isolated rotors were developed and validated [1-4]. Rotor-arm interactions and ducting will also be investigated as part of INTERNOISE, both for single and stacked rotors.

Kommentiert [WK1]: Albo albo, stacked z definicji są co-rotating

Kommentiert [WK2]: Będzie? W sumie dobry pomysł, bo wcześniej nie wyłapałem że mamy to w planie.

The objective of this project is to address the apparent research gap in the aeroacoustics of stacked rotors, for which little parametric data is available. Parameters such as axial and azimuthal rotor separation, respective rotor diameters and blade geometries and rotational speed were investigated in limited studies, but no extensive investigation of the interplay between those parameters has been published to date.

Methodology

Both computational and experimental methods are utilized in this study. The computational work involved analysis of aerodynamics of stacked rotors using a Reynolds-Averaged Navier-Stokes (RANS) solver, followed by aeroacoustic analysis based on Ffowcs Williams-Hawkings (FW-H) equations. This approach enables high-fidelity analysis of aeroacoustic interactions between rotor blades and their influence on the efficiency of the system.

The experimental part of the study was carried out using the anechoic chamber and the test stand previously validated for single rotors in the SILENT ROTOR project. The rotors were mounted on an extended axle of a single electric motor, with both thrust and torque meters embedded within the fairing. Several hardware and software improvements were made since the commissioning of the test stand, improving the precision and accuracy of thrust, torque and rotational speed measurements, including a low-pass filter on the torque sensor amplifier. The anechoic condition in the chamber was previously validated down to 125 Hz. However, the current lack of an anechoic wind tunnel prevents tests of forward flight, therefore the tests were limited to the hover condition.

Results

The first experimental campaign involved tests of two 2-blade APC 12x5.5 MR rotors, stacked at tip-to-tip axial separations between 9.5 mm and 63.5 mm. The azimuthal position of both rotors was fixed at several values between -60° and 60°, and they were tested at a range of RPM values. The presentation introduces the aerodynamic and acoustic characteristics of the setup, focusing on trends within the search space defined by the three tested parameters. Particular focus is placed on the noise spectra, including motor noise, which is a common challenge in aeroacoustic testing of rotors. A summary of the efforts to reduce and shield motor noise is presented, along with some comparative results showing the effect of those efforts, and the impact of mechanical noise on rotor evaluation. Finally, an outline of planned work is presented, including the design of an extension for the test stand, which will enable testing of ducted configurations and rotor-arm interactions.

Numerical analyses were performed for a range of cases to allow direct comparison with the experimental results. Analysis of results and trends obtained from experimental and computational studies serves as a validation of the computational methodology, which can be used in a design optimisation process. Apart from the

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quantitative analysis of trends within the search space, an attempt to qualitatively explain the effects of interactions between rotors is made, in order to expand the understanding of the stacked rotor setup.

References

[1] A. Sieradzki, P. Kekus-Kumor, W. Klimczyk, "Validation of a surrogate-based methodology for low-noise UAV/UAM rotor design", 49th European Rotorcraft Forum (ERF2023), Bückeburg, Germany, 5-7 September 2023

[2] P. Kekus-Kumor, A. Sieradzki, "Experimental investigation of unmanned air vehicle rotor aeroacoustics using benchmark geometries", 52nd International Congress and Exposition on Noise Control Engineering (Inter-noise 2023), Chiba, Japan, 20-23 August 2023

[3] W. Klimczyk, A. Sieradzki, "RANS-based aeroacoustic global sensitivity study and optimization of UAV propellers", Aerospace **2023**, 10, 306

[4] W. Klimczyk, A. Sieradzki, "Propeller aeroacoustic models in variable-fidelity design optimization", 33rd Congress of the International Council of the Aeronautical Sciences (ICAS 2022), Stockholm, Sweden, 4-9 September 2022