

EXPERIMENTAL INVESTIGATION AND AEROELASTIC CHARACTERISATION OF A MULTIROTOR SYSTEM

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ABSTRACT

Electric Vertical Take-Off and Landing (eVTOL) vehicles have established a new frontier in sustainable aviation, utilising Distributed Electric Propulsion (DEP) architectures where multiple rotors are distributed along the wingspan. However, the placement of multiple propulsion units on flexible airframes renders these configurations susceptible to dynamic challenges such as resonance, high-cycle fatigue and instability, posing a significant aeromechanical challenge for certification. To address some of these challenges, specialised experimental test rigs, such as the Maryland Tiltrotor Rig (MTR) [1] and the ATTILA testbed [2], were previously developed. While these campaigns successfully quantified the influence of hub kinematics on stability, they were limited to single-rotor architectures [3]. Consequently, these benchmarks could not explore the impact of rotor-rotor interactions on the dynamic characteristics and stability boundaries of DEP systems.

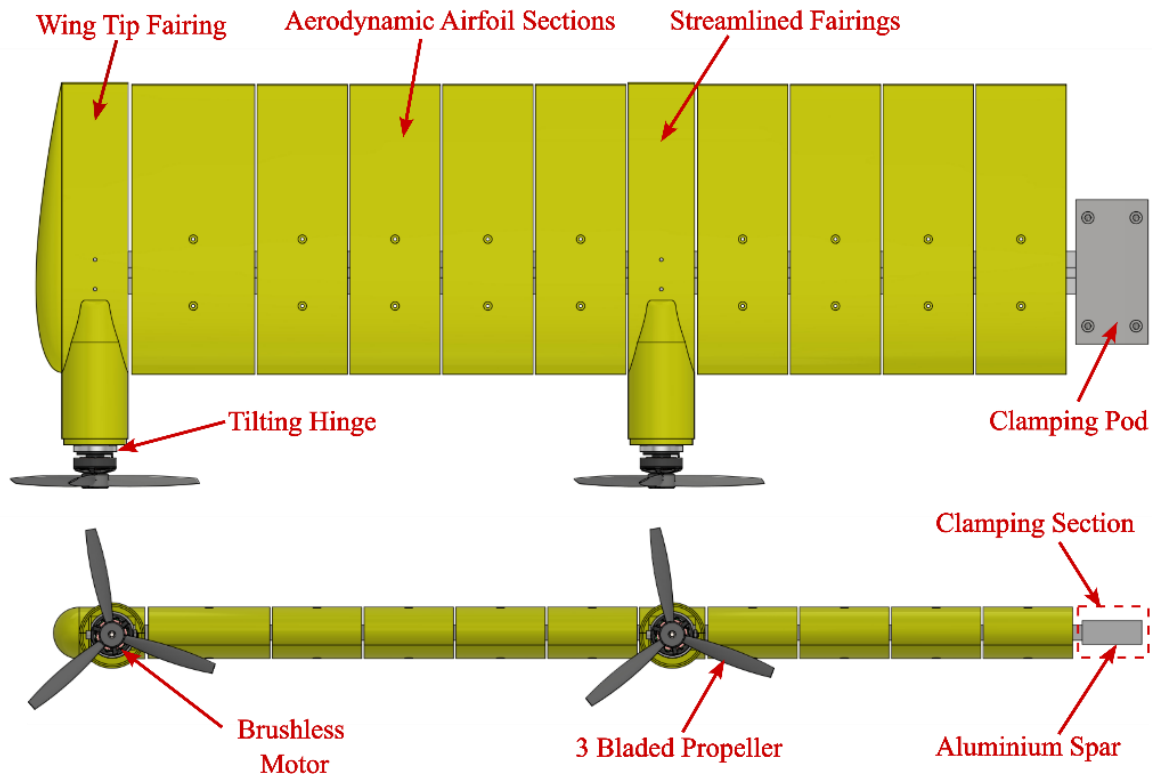


Figure 1: CAD visualisation of the dynamically scaled Bristol Multirotor Test Rig configured with dual-rotor DEP architecture for aeroelastic characterisation.

To address this gap, the Bristol Multirotor Test Rig was developed to investigate these dynamic interactions explicitly. Previous investigations in wind-off conditions presented at the ERF 2025 conference with this rig [4], revealed that rotor-rotor coupling in tilting multirotor systems gives rise to complex modal phenomena, including modal veering with mode shape swapping,

increased modal density, and the emergence of gyroscopically highly sensitive whirling modes [4]. Building on that initial structural dynamic characterisation, the objective of the current research is to experimentally investigate the influence of propeller and wing aerodynamic loads on the vibration performance, modal and stability characteristics.

The experimental campaign is conducted in the University of Bristol Pressure Neutral Wind Tunnel, utilising the dynamically scaled Bristol Multirotor Test Rig. To adapt the previously developed validated structural rig for a representative aeroelastic test campaign, the spar is encased in segmented 3D-printed aerodynamic airfoils, and the rotor-arm assemblies were fitted with fairings to provide streamlined aerodynamic shapes, as shown in Figure 1. The rig features a dual-rotor configuration with adjustable spanwise spacing to vary rotor-rotor interactions (Figure 2). Rotor speed (RPM) sweeps were performed at discrete increments of wind tunnel air speed from 5 m/sec to 35 m/sec. The system's aeroelastic response is characterised using Operational Modal Analysis (OMA), relying on ambient flow turbulence to excite the structure. Stochastic Subspace Identification (SSI) was applied to extract modal properties, using harmonic filtering to separate rotor harmonics from the structural response.

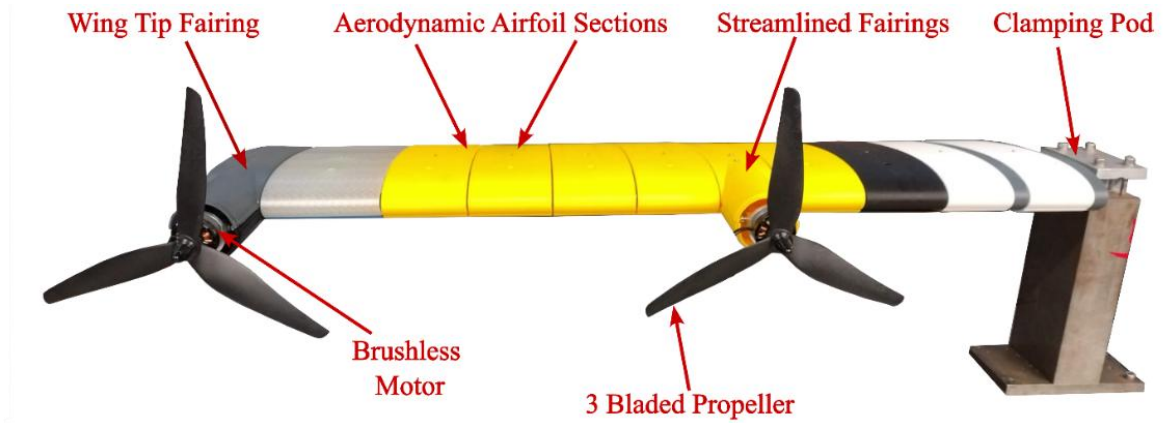


Figure 2: The assembled Bristol Multirotor Test Rig configured with dual-rotor DEP architecture for aeroelastic characterisation.

This paper presents the evolution of experimentally-identified natural frequencies and modal damping values with changes in controlled test parameters. The analysis also reveals the influence of aerodynamic loading on the complex model interactional phenomenon previously analysed in wind-off conditions using FE models [4]. Finally, the paper provides initial experimental insights into the stability of the coupled dual-rotor system, indicating the potential impact of rotor-rotor dynamic coupling.

References

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