EXPERIMENTAL INVESTIGATION OF NONLINEAR WHIRL-FLUTTER IN A 2-DOF ROTOR-PYLON SYSTEM

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ABSTRACT

Whirl flutter is a key aeroelastic concern for modern rotor systems, particularly in emerging electric aircraft configurations where propellers are mounted on flexible supports and may undergo significant off-axis motion. Classical studies, including Reed's original two-degree-of-freedom (DoF) formulation and subsequent rig-based experiments, have established the main aerodynamic and gyroscopic mechanisms driving whirl flutter. However, many existing experimental studies have focused primarily on linear behaviour, offering limited insight into the nonlinear phenomena that arise once instability has been triggered. Consequently, the post-onset dynamics of whirl flutter, particularly the formation and evolution of nonlinear oscillations remain poorly understood.

The study of this paper aims to experimentally investigate the nonlinear behaviour that emerges pre and post the onset of whirl flutter in a fully coupled two-degree-of-freedom rotor-pylon configuration. Particular attention is placed on characterizing the development of stable and unstable limit-cycle oscillations (LCOs), their amplitude and frequency content, and the manner in which pitch- coupling shapes the resulting motion. By focusing on the post-critical regime rather than the onset itself, the study seeks to provide new experimental insight into the mechanisms governing nonlinear whirl dynamics in propeller systems.

To support this investigation, a compact experimental rig was developed featuring a custom 2-DoF joint assembly with two embedded absolute magnetic encoders that provide simultaneous, high-resolution measurement of pitch and yaw angles. The rig will be operated in the University of Bristol's vertical wind tunnel where rotor speed and wind speed can be controlled independently, allowing systematic exploration of the conditions under which nonlinear behaviour emerges. Furthermore, a Reed-type numerical model, extended to include appropriate geometric coupling and gravitational effects, is used to aid interpretation of the measured dynamics. An overview of the experimental rig is shown in Figure 1.

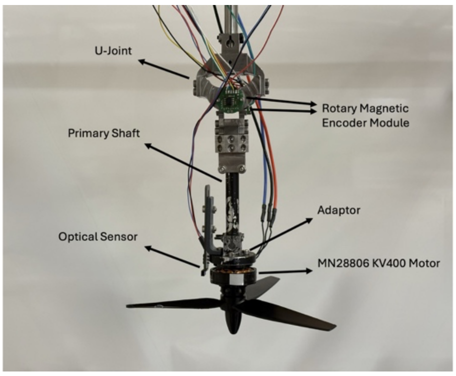

Figure 1. Experimental rotor–shaft rig featuring a two-degree-of-freedom joint with embedded absolute magnetic encoders for simultaneous measurement of pitch and yaw motion.

The initial results indicates that rig can undergo whirl flutter instability, where the stability boundary was influenced by the wind speed and the propeller rotational speed. The results also revealed that at wind speeds below the linear whirl flutter condition, large enough perturbation can still lead to diverging oscillations, indicating the presence of unstable LCOs and a subcritical whirl flutter (Hopf bifurcation point). The final paper will present a combined experimental and numerical characterisation of post-onset whirl flutter behaviour. The experimental results will include transient time-series illustrating the initial growth and subsequent saturation of oscillations; phase-portrait representations showing the evolution of coupled whirl trajectories into stable or slowly drifting LCOs; and frequency-domain analysis capturing the dominant frequencies and harmonic structure of the nonlinear response. Stability diagrams will be used to identify the operational conditions under which these nonlinear motions arise. Comparison with the numerical model will clarify where linear predictions remain adequate, where nonlinear effects become dominant, and how two-degree-of-freedom coupling modifies the overall aeroelastic behaviour.

The findings are expected to provide one of the first detailed experimental characterizations of nonlinear pitch-yaw whirl dynamics, supplying the data required to improve modelling of post-onset behaviour and offering new insight into the mechanisms that govern LCO formation in rotor systems.