AEROELASTIC STABILITY ANALYSIS OF WING-MULTI-PROPELLER SYSTEMS UNDER AERODYNAMIC INTERACTIONS USING THE UNSTEADY VORTEX-LATTICE METHOD

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ABSTRACT

The design of modern aircraft has been driven by the search for energy efficiency and low emissions, leading to increased interest in distributed electric propulsion concepts[1]. To ensure the feasibility of these concepts, aerodynamic efficiency must be maximized, favoring designs with lightweight, high-aspect-ratio wings[2]. When combined with distributed propellers, these slender, very flexible wings may exhibit aeroelastic instabilities such as wing and whirl flutter[3].

Wing-propeller flutter boundaries are sensitive to aerodynamic interference effects[4,5], yet the influence of these effects remains poorly understood, particularly for multi-propeller configurations. Most previous work[6] has relied on the viscous vortex-particle method (VVPM), a mid-fidelity aerodynamic modeling approach that is meshless and captures complex wake geometries alongside viscous effects. However, VVPM-based aeroelastic stability results have not been extensively compared with alternative modeling approaches[7,8]. In addition, the relative contributions of three-dimensional (3D) aerodynamics and wing-propeller aerodynamic interference have not been quantified.

This paper will investigate the aeroelastic stability of a wing-propeller system with multiple distributed propellers. The paper will bring two contributions: (i) quantification of the influence of 3D aerodynamic effects versus aerodynamic interference effects on flutter points; and (ii) evaluation of the unsteady vortex-lattice method (UVLM)[9] as a potential-flow alternative to the VVPM for aeroelastic stability analysis. The wing and propeller structural dynamics will be modeled using linear Euler-Bernoulli beam finite elements and Reed's two-degree-of-freedom model, respectively[10]. Wing and propeller aerodynamics will both be modeled using the UVLM, with and without aerodynamic interference, the latter case produced via decoupled aerodynamic influence coefficient matrices. The study will focus on the wing-propeller test case by Chang et al.[11], which will be modified to produce multi-propeller variants. The coupled aeroelastic model will be used to predict flutter points via time-domain simulations for varying system parameters. The results will be compared with those based on the VVPM, being generated in a parallel effort[12].

The final paper will include: (i) a literature review on the aeroelastic analysis of wing-propeller systems; (ii) a description of the modeling approaches and test case; (iii) a parametric aeroelastic stability analysis; (iv) modeling insights for aeroelastic stability analysis of aircraft featuring distributed propellers.

The study is expected to elucidate the relative contributions of 3D and aerodynamic-interference effects on aeroelastic stability of wing-multi-propeller systems and the effectiveness of VVPM and UVLM aerodynamics to predict their flutter boundaries, including their individual advantages and limitations. These contributions will advance both the current understanding of wing-propeller aeroelastic instabilities and the associated modeling and analysis capabilities.

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