

AEROELASTIC OPTIMIZATION OF STICK MODELS FOR PARAMETRIC FLUTTER ANALYSIS IN BLENDED-WING-BODY AIRCRAFT

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Abstract

Blended-wing-body aircraft offer significant promise in future aircraft design due to their highly integrated configuration that improves aerodynamic efficiency, reduces structural weight, and enhances overall performance. At the same time, this unconventional layout gives rise to complex aeroelastic interactions, making it essential to understand the coupling between aerodynamic forces and structural dynamics from the early design stages.

This work assesses the aeroelastic behavior of a blended-wing-body (BWB) aircraft configuration and proposes a model order reduction framework to enable parametric studies of aerodynamic shape and structural properties. A high-fidelity baseline aeroelastic model is first developed and evaluated under ultimate loading conditions in accordance with certification requirements. Modal analysis identifies the dominant bending and torsional modes governing the dynamic response, while the modal assurance criterion (MAC) is used to assess modal coupling. Aeroelastic analyses reveal two critical instabilities within the flight envelope: symmetric and antisymmetric bending-torsion flutter (BTF). A reduced-order stick model was calibrated through an optimization-based workflow to replace the flexible wing in a generalized finite element model (GFEM) of the aircraft. This condensation approach reduces the computational cost of aeroelastic analyses while preserving the model's physical interpretability. Three case studies were conducted to match the static deformation, modal response, and aeroelastic behavior of the full aircraft GFEM. Error metrics were introduced to quantify discrepancies in displacement, twist, natural frequencies, and mode shapes.

Two novel aeroelastic metrics are proposed: an eigenvalue error metric based on the Error Vector Magnitude (EVM) concept, and a complex mode shape metric tailored to complex aeroelastic eigenvectors. The optimized model predicts flutter speeds with less than 3% error and accurately reproduces the underlying instability mechanisms, while reducing computational cost.

To further investigate the flutter mechanisms of the BWB configuration, the reduced-order model is used in a parametric study involving six geometric and structural parameters. Across the 600 configurations evaluated, the governing instability was bending-torsion flutter (BTF). The study characterizes how flutter mechanisms evolve throughout the design space and shows that the proposed methodology can identify configuration changes capable of increasing flutter speed by up to 30%.