AEROELASTIC ANALYSIS AND OPTIMIZATION OF WING DESIGN PARAMETERS AND VAT FIBER PATHS BASED ON ISOGEOMETRIC ANALYSIS

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ABSTRACT

Isogeometric Analysis (IGA) is capable to achieve exact geometry representation, higher-order continuity, and flexible refinement strategies, which holds significant importance for the analysis of wings with Variable angle tow (VAT) fibers. Meanwhile, VAT fiber placement introduces spatially varying stiffness characteristics that modify the bending–torsion coupling behavior of wings, thereby jointly influencing their structural dynamic and aeroelastic performance together with wing design parameters.

This paper proposes a collaborative optimization framework for wing design parameters and VAT fiber layup parameters in the preliminary design stage, based on IGA. Non-uniform rational B-splines (NURBS) with $Cp-1$ continuity are employed to provide representations of the wing surface and the paths of VAT fiber. We established the structural dynamics model based on the third-order shear deformation theory (TSDT), and an aeroelastic coupling equation is constructed by integrating Theodorsen aerodynamic theory with the strip theory. The flutter characteristics of VAT composite wings under different parameter combinations are systematically investigated and validated against results from commercial software. In addition, the influences of various layup parameters on the wing elastic axis, bending–torsion coupling deformation, and flutter speed are comparatively evaluated. On this basis, a genetic algorithm is employed to optimize wing design parameters and the optimal fiber paths for different flight conditions.

The close agreement between the isogeometric aeroelastic analysis results presented in this study and the structural dynamic analysis results obtained from commercial software demonstrates that the proposed IGA-based structural dynamics and aeroelastic modeling framework can accurately capture the dependence of wing aeroelastic performance on global design parameters, fiber trajectories, and other key variables. The developed approach is well suited for large-scale optimization at the conceptual design stage, in which geometric parameters and fiber paths are simultaneously considered, enabling efficient exploration of the aeroelastic design characteristics of curvilinear fiber wings. In addition, the method is applicable to overall aircraft design problems with specific requirements on modal frequencies, mode shapes, and flutter-dominant modes.

This study aims to provide a method for the analysis of complex wing structures with VAT fibers by establishing a geometry-consistent aeroelastic analysis framework based on IGA, thereby bridging the gap between design and analysis models and enhancing the optimization efficiency of VAT composite wings.

Keywords: Isogeometric Analysis, Aircraft design, Aeroelasticity, Variable Angle Tow Fiber